Mathematics Education in the Digital Era

Tom Lowrie
Robyn Jorgensen (Zevenbergen) *Editors*

Digital Games and Mathematics Learning

Potential, promises and pitfalls

Springer

www.allitebooks.com

Mathematics Education in the Digital Era

Volume 4

Editorial Board:

Marcelo Borba, State University of São Paulo, São Paulo, Brazil
Rosa Maria Bottino, CNR – Istituto Tecnologie Didattiche, Genova, Italy
Paul Drijvers, Utrecht University, the Netherlands
Celia Hoyles, University of London, London, UK
Zekeriya Karadag, Bayburt University, Turkey
Stephen Lerman, London South Bank University, London, UK
Richard Lesh, Indiana University, Bloomington, USA
Allen Leung, Hong Kong Baptist University, Hong Kong
John Mason, Open University, UK
Sergey Pozdnyakov, Saint-Petersburg State Electro Technical University, Saint-Petersburg, Russia
Ornella Robutti, Università di Torino, Torino, Italy
Anna Sfard, Michigan State University, USA & University of Haifa, Haifa, Israel
Bharath Sriraman, University of Montana, Missoula, USA
Anne Watson, University of Oxford, Oxford, UK

www.allitebooks.com

The Mathematics Education in the Digital Era (MEDE) series explores ways in which digital technologies support mathematics teaching and the learning of Net Gen'ers, paying attention also to educational debates. Each volume will address one specific issue in mathematics education (e.g., visual mathematics and cyber-learning; inclusive and community based e-learning; teaching in the digital era), in an attempt to explore fundamental assumptions about teaching and learning mathematics in the presence of digital technologies. This series aims to attract diverse readers including: researchers in mathematics education, mathematicians, cognitive scientists and computer scientists, graduate students in education, policy-makers, educational software developers, administrators and teachers–practitioners.

Among other things, the high quality scientific work published in this series will address questions related to the suitability of pedagogies and digital technologies for new generations of mathematics students. The series will also provide readers with deeper insight into how innovative teaching and assessment practices emerge, make their way into the classroom, and shape the learning of young students who have grown up with technology. The series will also look at how to bridge theory and practice to enhance the different learning styles of today's students and turn their motivation and natural interest in technology into an additional support for meaningful mathematics learning. The series provides the opportunity for the dissemination of findings that address the effects of digital technologies on learning outcomes and their integration into effective teaching practices; the potential of mathematics educational software for the transformation of instruction and curricula; and the power of the e-learning of mathematics, as inclusive and community-based, yet personalized and hands-on.

Titles coming soon:

Students Solving Mathematical Problems with Technology by Susana Carreira, Keith Jones, Nélia Amado, Hélia Jacinto and Sandra Nobre (2015)
Digital Technologies in Designing Mathematics Education Tasks: Potential & Pitfalls edited by Allen Leung and Anna Baccaglini-Frank (2016)
Learning and Teaching Mathematics in The Global Village: The Semiotics of Digital Math Education by Marcel Danesi (2016)
Computations and Computing Devices in Mathematics Education before the Advent of Electronic Calculators edited by Alexei Volkov and Viktor Freiman (2016)

Book proposals for this series may be submitted per email to Springer or the Series Editors.

—Springer: Natalie Rieborn at Natalie.Rieborn@springer.com
—Series Editors: Dragana Martinovic at dragana@uwindsor.ca and Viktor Freiman at viktor.freiman@umoncton.ca

More information about this series at http://www.springer.com/series/10170

www.allitebooks.com

Tom Lowrie • Robyn Jorgensen (Zevenbergen)
Editors

Digital Games and Mathematics Learning

Potential, Promises and Pitfalls

Springer

www.allitebooks.com

Editors
Tom Lowrie
Faculty of Education, Science,
Technology and Mathematics
University of Canberra
Canberra
Australian Capital Territory
Australia

Robyn Jorgensen (Zevenbergen)
Faculty of Education, Science,
Technology and Mathematics
University of Canberra
Canberra
Australian Capital Territory
Australia

ISSN 2211-8136 ISSN 2211-8144 (electronic)
Mathematics Education in the Digital Era
ISBN 978-94-017-9516-6 ISBN 978-94-017-9517-3 (eBook)
DOI 10.1007/978-94-017-9517-3

Library of Congress Control Number: 2015931215

Springer Dordrecht Heidelberg New York London
© Springer Science+Business Media Dordrecht 2015
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

Springer is a brand of Springer Netherlands
Springer Netherlands is part of Springer Science+Business Media (www.springer.com)

www.allitebooks.com

Contents

www.allitebooks.com

www.allitebooks.com

Contributors

Antri Avraamidou is a doctoral candidate at the University of Leeds in the area of Mathematics and ICT. She also works as a Research Associate in the Department of Educational Technology at Cyprus Pedagogical Institute and as a Lecturer in Educational Technology at the University of Nicosia. Her PhD study explores the emergence of mathematical meanings through collaborative gameplay of the commercial video game The Sims 3, in out-of-school settings. In addition, through Cyprus Pedagogical Institute's European Union-funded projects, Antri has expanded her level of research expertise on ICT and Education, in-service teacher ICT training, visualised learning design methodologies technology and the use of ePortfolio and eAssessment. She has published a number of journal articles on visualised learning design and gameplay.

Catherine Beavis is a Professor of Education in the School of Education and Professional Studies at Griffith University (Australia). She teaches and researches in the areas of English and literacy curriculum, digital culture, young people and new media. Her work has a particular focus on the changing nature of text and literacy, and the implications of young people's experience of the online world for Education. Catherine's research investigates computer games and young people's engagement with them, exploring the ways in which games work as new textual worlds for players, embodying and extending 'new' literate and multimodal literacies and stretching and changing expectations of and orientations towards literacy and learning. Recent research includes Australian Research Council projects: *Serious Play: Using Digital Games in School to Promote Literacy and Learning* (Beavis, Dezuanni, O'Mara, Prestridge, Rowan, Zagami and Chee, 2012–2014) and *Literacy in the Digital World of the Twenty First Century: Learning from Computer Games* (Beavis, Bradford, O'Mara and Walsh, 2007–2009).

Marcelo C. Borba is a Professor of the Graduate Program in Mathematics Education and of the Mathematics Department of UNESP (State University of São Paulo) in Brazil, where he chairs the research group GPIMEM. Marcelo researches the use of digital technology in mathematics education, online distance education, modeling as a pedagogical approach and qualitative research methodology. He is a

www.allitebooks.com

member of the editorial board for *Educational Studies in Mathematics* and an Associate Editor of *ZDM*. Marcelo has delivered invited presentations internationally in countries such as Australia, Canada, Denmark, Iceland, Mozambique, Mexico, Germany, New Zealand, Italy, Colombia, Argentina and the United States of America. He was a member of the education committee of the main research funding agency of Brazil for 4 years (2008–2011). He has also been a member of the program committee for several international conferences. Marcelo has published several books, book chapters and refereed papers in Portuguese and in English. He is the editor of a collection of books in Brazil titled *Trends in Mathematics Education* (published by Springer Science+Business Media, Inc.), which have been published over the last 12 years and include 26 books to date.

Terry Bossomaier is Strategic Research Professor of Computer Systems in the Faculty of Business at Charles Sturt University. He graduated from the Universities of Cambridge and East Anglia and has carried out research in diverse areas, from sensory information processing to parallel computation. He is the author/co-author of four books, co-editor of two more and the author of numerous papers. His most recent centres on using information theory to predict tipping points in complex systems. He has had a long-time interest in games and set up the first computer games degree course in Australia, which has been running successfully for over a decade.

Nigel Calder is a Senior Lecturer for the University of Waikato based at the Tauranga campus in New Zealand. His research interests are predominantly in the use of digital technologies in mathematics education. Nigel also is interested in student-centred inquiry learning, algebraic thinking, and problem-solving. He has expertise in a critical approach to contemporary hermeneutics and participatory action research. His present research projects are: examining the influence of mobile technologies on the attitudes and engagement of 16–18 year old Youth Guarantee students in numeracy and literacy, and how mathematical thinking emerges through student-centred inquiry learning in secondary schools. Nigel also authored the book: *Processing Mathematics through Digital Technologies: The Primary Years* (Sense Publishers, 2011) and has published various book chapters and journal articles.

Cesare Fregola is Professor of *Didactics of Mathematics for the Integration* in the Faculty of Primary Education at the University of L'Aquila in Italy. He also leads the Experimental Pedagogy Laboratory at the Università Roma Tre of Rome, Italy. He is a PTSTA (E) Provisional Teaching and Supervising Transactional Analyst in Educational field for the EATA (European Association Transactional Analysis). Cesare led and currently participates in research on emotional, cognitive, meta-cognitive and socio-relational dimensions in the learning processes of mathematics as well as for the design, and realization of learning environments for lifelong learning. He has authored monographs, articles and papers of both national and international relevance. He has also co-edited (along with Angela Piu) and written a number of chapters in the book, *Simulation and Gaming for Mathematical Education: Epistemology and Teaching Strategies* (IGI Global, 2010).

www.allitebooks.com

Begoña Gros is Full Professor in the Faculty of Education at the University of Barcelona in Spain. She is currently the coordinator of the research group, *The Design of Environment and Resources for Learning*. Her specialisation focuses on studying the integration of digital media in education and learning, and the use of video games. Begoña has published a number of journal articles and book chapters on digital media in education and learning, including *The Design of Games-Based Learning Environments* (2007), *Game-Based Learning: A Strategy to Integrate Digital Games in Schools*, *Beyond the Net Generation Debate: A Comparison of Digital Learners in Face-to-Face and Virtual Universities* (2012), and *Supporting Learning Self-Regulation through a PLE* (2013).

Kevin Larkin is a Lecturer in Mathematics Education in the School of Education and Professional Studies at Griffith University in Australia. Kevin's research interests and expertise include student attitudes to mathematics in primary school, the experience of transition into high school and its implications for mathematics education, mathematics education for pre-service teachers in blended and online contexts, and the nexus between digital technologies and mathematics education. He is involved in four different research teams investigating these research interests, including the AU$3.2 million research project funded by the Office for Learning and Teaching, *Step up! Transforming Mathematics and Science Pre-service Secondary Teacher Education in Queensland.*

Tracy Logan is Assistant Professor in the Faculty of Education, Science, Technology and Mathematics at the University of Canberra. As an early career academic, most of Tracy's research has emerged from involvement in five Australian Research Council (ARC) Discovery grants. Her areas of strength reside within students' spatial reasoning, mathematics assessment and the use of digital tools for mathematics sense making. Tracy's research involves a range of mixed-paradigm research methodologies, including data collection in longitudinal mass-testing situations; one-on-one interviews; cross-country comparisons of students' numeracy development; student and teacher focus groups; longitudinal case studies; and stimulated recall. Tracy is currently undertaking a PhD at the University of Canberra in the area of mathematics education, with a focus on secondary data analysis utilising a sophisticated framework that analyses both quantitative and qualitative data.

Marcus V. Maltempi is a Professor of the graduate program in Mathematics Education and of the undergraduate course in Computer Science of UNESP (State University of São Paulo) in Brazil. His primary research interests lie around the use of information and communication technologies in mathematics education, including mathematical modeling, online distance education and teacher education. Marcus has directed or co-directed ten research projects, all of which have focused on the use of ICT in mathematics education. He currently directs a project that investigates mathematical modeling in the reality of the cybernetic world. He is well published in Portuguese and has some papers in English (in proceedings from Psychology of

www.allitebooks.com

Mathematics Education [PME] and the Congress of European Research in Mathematics Education [CERME] as well as *ZDM: The International Journal of Mathematics Education*).

John Monaghan is Professor of Mathematics Education at the University of Agder, Norway. Prior to this he was at the University of Leeds for 25 years and a school teacher for 10 years before that. John enjoys research and teaching (but not admin). His research interests are firmly centred in mathematics education and include learners' understanding of algebra and calculus, linking school and out-of-school mathematics, the use of technology in learning and in teaching. In his leisure time he is a keen gamer and has enjoyed bringing gaming into his professional interests in recent years. He retains his link with the University of Leeds through the supervision of doctoral students, one of which, Antri, is a co-author in a chapter in this book.

Meagan Rothschild is an Assessment and Design Specialist at WIDA and a PhD candidate at the University of Wisconsin-Madison. She made the courageous leap to the chilly Midwest from balmy Hawaii to pursue a PhD and work with the Games, Learning, and Society Center. Prior to her move, Meagan served as the Instructional Designer for Cosmos Chaos!, an innovative video game designed to support struggling fourth grade readers developed by Pacific Resources for Education and Learning (PREL). Her experience at PREL also included the design of a violence and substance abuse prevention curriculum for Native Hawaiian students, using an interdisciplinary approach that merged health and language arts content standards to support literacy-driven prevention activities. Meagan has 6 years of experience in the Hawaii Department of Education system serving in varied roles, including high school classroom teacher, grant writer and manager, technology coordinator, and Magnet E-academy coordinator. Meagan has a BA and MEd from the University of Hawaii at Manoa, with undergraduate studies in Hawaiian Language and special education, and an MEd in Educational Technology. As a PhD candidate in Digital Media and Learning at the University of Wisconsin-Madison, her work now focuses on developing and researching multimedia environments that merge research-based learning principles with interactive/gaming strategies to engage learners. She specifically focuses on the role of play to not only provide opportunities for deeper learning, but to provide relevant contexts for learners to demonstrate content knowledge, challenging traditional views of assessment practices.

Richard N. Van Eck is Associate Dean for Teaching and Learning and the founding Dr. David and Lola Rognlie Monson Endowed Professor in Medical Education at the University of North Dakota (UND) School of Medicine and Health Sciences at the University of North Dakota, in the United States of America. He has also served for 11 years as a professor of Instructional Design and Technology at UND and for 5 years at the University of Memphis, Tennessee, where he was also a member of the Institute for Intelligent Systems. He has been studying games and learning since 1995 when he entered the PhD program at the University of South

Alabama and worked as an instructional designer or developer on several learning games there, including Adventures in Problem Solving (Texas Interactive Media Award 1999) and Ribbit's Big Splash (Gulf Guardian Award 2002; Environment Education Association of Alabama's 2002 Best Environmental Education Award). Since then he has been a researcher and designer on several other STEM games, including PlatinuMath (mathematics game for pre-service teacher education), Project NEO (science game for pre-service teachers), Project Blackfeather (programming game for middle school students), Contemporary Studies of the Zombie Apocalypse (mathematics game for middle school students) and Far Plane (leadership game for high school students and adults). Dr. Van Eck is a frequent keynote speaker nationally and internationally on the educational potential of videogames, and his scholarship on games, in this area includes dozens of books, chapters and refereed publications, and more than 75 presentations on games and learning including talks at TEDx Manitoba and South By Southwest. In addition to his work on serious games, Richard has also published and presented on intelligent tutoring systems, pedagogical agents, authoring tools, and gender and technology.

Rodrigo Dalla Vecchia is Coordinator of the Mathematics Teachers Education degree and Professor in the Graduate Program in Science and Mathematics Teaching at the Lutheran University of Brazil. Currently, his research is focused on the relationship between mathematical modeling and the reality of the cyber world. He published in Portuguese and has some papers in English (in proceedings from Psychology of Mathematics Education [PME], the Congress of European Research in Mathematics Education [CERME], and the International Community of Teachers of Mathematical Modelling and Applications [ICTMA]).

Aisha Walker is Associate Professor of Technology, Education and Learning at the University of Leeds where she is Programme Director of the MA Technology, Education and Learning. Her research areas include digitally-mediated communication, digital learning and children's engagement with digital technologies. She has published papers in journals such as the *Journal of Computer Assisted Learning, Education 3-13, Technology, Knowledge and Learning* and the *International Journal of Mobile and Blended Learning*, as well as chapters in a number of edited collections. Aisha is also co-author of *Technology Enhanced Language Learning: Connecting Theory and Practice* published by Oxford University Press (2013). More information is available at <http://www.education.leeds.ac.uk/people/academic/walker>.

Caroline C. Williams is a dissertator at the University of Wisconsin-Madison (specializing particularly in Mathematics Education in the Department of Curriculum and Instruction), and affiliated with the Games+Learning+Society group. Her dissertation involves designing a Little Big Planet 2 game to teach fractions and linear functions, and she specializes in research involving middle school students, mathematics, and all things digital media. Caro has presented and published on a wide variety of topics, including building in Little Big Planet, mathematics in World of Warcraft forum posts, using gestures to support mathematical reasoning, example usage in mathematical proof processes, gender and mathematics, and learning trajectories in linear, quadratic, and exponential functions.

Kim Woodland works in the Research Institute for Professional Practice, Learning and Education (RIPPLE) at Charles Sturt University in Australia. She has worked as a research assistant in mathematics education, focusing on spatial reasoning and visual imagery, including assisting with a number of Australian Research Council funded projects—including *Mathematics in the Digital Age: Reframing Learning Opportunities for Disadvantaged Indigenous and Rural Students*. She has also assisted in the editorial process for a range of books, book chapters, journal articles and conference papers in mathematics education for primary school students.

About the Editors

Robyn Jorgensen (Zevenbergen) is a Professor of Education: Equity and Pedagogy at the University of Canberra. Her work has been focused on issues of equity and access in relation to mathematics education. This work has sought to understand the ways in which mathematics practices are implicated in the success (or not) of students who have been traditionally marginalized in the study of school mathematics. Her work usually draws on the theoretical frameworks offered by French sociologist, Pierre Bourdieu, to better understand the ways in which practices within the field of mathematics education are implicated in the (re)production of equity and inequities.

Tom Lowrie is a Centenary Professor at the University of Canberra. Tom has an established international research profile in the discipline area of mathematics education and he has attracted considerable nationally competitive funding from the Australian Research Council. A substantial body of Tom's research is associated with spatial sense, particularly students' use of spatial skills and visual imagery to solve mathematics problems. He also investigates the role and nature of graphics in mathematics assessment. Tom has investigated the extent to which digital technologies impact on the education community including teachers, children, and their parents, as well as children's engagement in out-of-school settings. A particular focus of Tom's work has been on disadvantaged students (particularly Indigenous students and students living in remote areas). He was selected to publish an entry on rural and remote mathematics education in the Springer *Encyclopedia of Mathematics Education* (2014) and is co-author of the book, *Mathematics for Children: Challenging Children to Think Mathematically* (the most widely distributed undergraduate mathematics book in Australia and published in its fourth edition in 2012 by Pearson Australia).

Digital Games and Learning: What's New Is Already Old?

Tom Lowrie and Robyn Jorgensen (Zevenbergen)

Keywords Technology · Mathematics education · Digital · Literacy · Games environment · Digital environment · Authentic problem solving · Mathematics · Dynamic visual imagery · Spatial reasoning · Dynamic imagery

Context

The genesis of this manuscript was inspired by a series of presentations (in 2011) undertaken via a Discussion Group at the 35th conference of the International Group for the Psychology of Mathematics Education held in Ankara, Turkey. In fact, several of the participants in the Discussion Group are chapter authors. Collectively, the authors of this manuscript were given the challenge to consider the affordances (or not) of digital games for mathematics learning. Their international perspectives are drawn from a diverse range of cognitive, psychological and socio-cultural viewpoints, from foundations within and outside mathematics education. It was not our intent to have a book that was driven solely by data, but rather to make a contribution to the field by drawing on a wide range of authors whose methodologies and approaches would create a discussion forum for considering the worth (or not) of games in bringing about better ways of teaching and learning mathematics. At the same time, we were also interested in seeing the affordances that this new genre may create for new forms of learning and mathematics.

The manuscript addresses the potential, promises and pitfalls of digital games for mathematics learning by measuring, monitoring and analysing the development of students' sense making as they engage in games technologies, both in- and out-of-school. Technology is clearly a catalyst for significant educational and social change—and although technology has become intrinsic to most of our daily practices, education systems rely much less on technology than is the case in society

T. Lowrie (✉) · R. Jorgensen (Zevenbergen)
Faculty of Education, Science, Technology and Mathematics,
University of Canberra, Canberra, Australia
e-mail: thomas.lowrie@canberra.edu.au

R. Jorgensen (Zevenbergen)
e-mail: robyn.jorgensen@canberra.edu.au

© Springer Science+Business Media Dordrecht 2015
T. Lowrie, R. Jorgensen (Zevenbergen) (eds.), *Digital Games and Mathematics Learning,*
Mathematics Education in the Digital Era 4, DOI 10.1007/978-94-017-9517-3_1

more generally. As citizens, we have been forced to be adaptors of *digital* technology—from paying bills to how we decode a map. To date, education systems have been protected somewhat, and mathematics education in particular. Indeed, there is some sense that there may be some artificiality in terms of the potential for digital tools to radically reform education. It is in this context that we have actively sought to bring a broad collection of authors and perspectives to create a forum for debate.

In the last chapter of the book, a secondary data analysis of digital game impact over the past 5 years, Logan and Woodland (Chap. 14) highlight the influence digital games are having beyond the entertainment industry. They speculate that the current generation of children is experiencing a parallel education, with out-of-school learning highly influenced by gaming. They suggest that these children will "grow and compound the use of digital games in learning as they themselves become our future educators and policy-makers". Potentially, we are at the advent of a digital era that could impact dramatically on education and school classrooms. In the past, such expectations and predictions have had much less effect than initially conceived [remember Pappert's (1980) *Mindstorms*].

We trust that this book will provide readers with a relatively global perspective of the influence of digital games in education, and particularly the nature and role of gaming in mathematics education. We are mindful of the fact that digital technologies 'change' at a much greater rate than education curricula systems, and that today's new hardware or peripherals are likely to be redundant in a few years. Nevertheless, gaming may well be the next major influence on learning and education, and it is certainly the case that mathematics has a role in new developments and initiatives.

Positing Digital Games Within Literacy Contexts

In the field of literacy education, there is a strong recognition of the possibility of the digital games environment creating new opportunities for literacy and literacy learning. Gee's (2003) seminal work with digital games has highlighted two salient features that may have application in the field of mathematics education. First are the opportunities for new forms of literacy that are made possible through the digitized literacy format of the games platforms. Second, the digital games environment itself creates and fosters new learning opportunities that appear to engage learners for long, sustained periods of time. Gee contends that much can be learnt from the principles that underpin the games technologies that need to be adopted into modern learning environments.

Gee (2003) has examined the digital games environments to explore the principles used by the gaming industry to engage players in games. As a highly competitive industry where millions of dollars can be spent on developing games, the industry has designed games that engage players for extended periods of time. Gee's principles have been used to justify reforms in education that will engage the students as they enter schools. Gee and his advocates argued that the current practices in school are failing to cater for today's learners (often termed 'digital natives'). He proposed that 36 principles used in games designs could radically offer new learning environments that cater for learning and learners in the digital era.

Drawing on three discourses (situated cognition, new literacy studies and connectionism), Gee provides a comprehensive account of the possibilities of games to create exciting and engaging learning opportunities. Primarily, Gee focuses on literacy learning and how the games environment allows for new forms of literacy and engagement in literacy texts. The literacy demands of these digital worlds are substantially different from the linear text models of the printed media that has dominated literacy since the industrial revolution. It is beyond the scope of this chapter to outline each of these principles in detail but we provide the full list here without description. Fundamental to Gee's principles are the notions that gamers identify with the game and develop an identity (and affinity) with the game that aids in the engagement with the game. Once in the game, the player then is further engaged through the underlying structures of the game where there is a progression through the game from simple activities that progressively increase in difficulty. As the player engages with these increasing complexities, he/she is strongly scaffolded through a range of design principles including low-failure and where failure is not public so that there is encouragement to engage with game. The game is also structured so that skills learnt in one level will be used and extended in subsequent levels. The principles are compelling and clearly work in the games industry. Given many of the principles mirror practices most educationalists value and indeed strive for, one could easily suggest a 'magic bullet' has been identified, at least in terms of literacy education.

Nevertheless, Gros (2007) argued that overall the field of research into digital games is fragmented, disjointed and has no real sense of boundaries. This is due, in part, to the burgeoning pace at which technology develops. Although there have been strong advocates supporting the notion that digital games may revolutionise education, others (Warschauer 2007) caution such support and take a more measured view in terms of the types and speed of reform that has emerged. One of the fundamental tenants for this book was to challenge the authors to consider the limitations in conjunction with the affordances of digital games for learning. It is here that this book contributes significantly to the series in which it is located.

Digital Games and Mathematics Thinking

Since the explicit positioning of literacy education within the digital games environment, researchers have begun to explore the possibilities for digital games to enhance learning of mathematical concepts and processes. Relatedly, problem solving in a digital games environment requires varying levels of goal-orientated decision making. In a mathematics context, Schoenfeld (2010) argued that such goal-orientated processing included three components, namely: (1) resources (general knowledge); (2) goals; and (3) orientations (including beliefs and dispositions).

He argued that most “in the moment” decision making had links to these three mathematics components. Fregola (Chap. 10) maintains that games environments promoted the process of mathematical abstraction, which included decision making about the characters and language of the environment. In a similar vein to that of Schoenfeld, he points out that problem solving consisted of a set of skills that included a self-regulatory that was mathematical in nature.

Collectively, much of the research in this area has been the catalyst for imagining the possibilities of the digital games environment to enable new ways of thinking and working mathematically. For example, Dalla Vecchia, Maltempi and Borba (Chap. 4) understand that the mathematical modeling that takes place in the process of electronic games construction may contribute to the mathematisation process, since the process considers the students’ choices and interests, and adopts learning frameworks which are essentially constructivist in nature. In particular, they raise issues about the potential role of mathematical modelling in creating new virtual environments within games contexts. It would seem to be the case that the more open-ended and multidirectional games become, the greater the need to model the environments mathematically.

Technology advances provide scope for digital games to become more complex and certainly more challenging. As a consequence, user engagement can be multidimensional and storylines can have realistic implications and outcomes. In fact, serious games tend to be more effective in terms of both learning and retention when compared to conventional instructional practices (Wouters et al. 2013). Bossomaier (Chap. 11) maintains that the potential and perhaps real impact of this burgeoning area of serious games “is the complex environment surrounding the game, the meta-game and affinity spaces. This rich, creativity extension of the gaming world offers in-depth, contextualised understanding”. It also offers huge potential for mathematical thinking, not only associated with problem solving but also the development of engagement in spatially and visually rich environments. However, as Bossomaier points out, “One of the huge gains, and possibly, one of the challenges, is integrating these powerful frameworks into conventional courses and educational program…”.

As Van Eck (Chap. 9) asserts, it is unwise to rely on the game as the source for learning development. Rather, a sound understanding of what embedded theories promote quality instructional design is required. As with many authors in this volume, he argues that sound psychological, cognitive and sociocultural principles must surround the games environment. This chapter outlines a model (one that encourages situated and authentic problem solving) that can be used with digital games to promote transfer and improve attitudes toward mathematics. In concert with the fundamental intent of the book, both Bossomaier and Van Eck acknowledge the games themselves cannot enhance learning opportunities—no matter how good the learning designs may be. Gros (Chap. 3) indicates this can only occur if user experiences are carefully linked to context and learning. Indeed, Gros maintains that this integrated understanding of the artifact (the game) and the process is critical since general perceptions of the usefulness of digital games to enhance learning are likely to grow in the immediate future. This rationale is based on the fact that the generation experiencing learning through games in the classroom today will expect such engagement when they reach tertiary education. Moreover, he predicts that teachers will receive tools and learning materials developed specifically for game-based learning that will cater for groups of learners with different skills, levels and competencies. This notion of inevitability is certainly apparent within the Logan and Woodland chapter.

Mathematics and Digital Games in Schools

There are a number of approaches in mathematics education where the possibilities of digital games are explored. The types of games used as the basis of this research vary considerable, making it challenging to find effective definitions of what constitutes a 'digital game'. As Rothschild and Williams (Chap. 8) point out, the availability of products and applications to enhance basic mathematics and literacy skills is overwhelming, even at the early childhood and preschool levels. They argue that software developers "would be well advised to move beyond enumeration activities and look into supporting the transition from enumeration to number application" since seemingly simple cognitive progression contains numerous leaps toward higher-order number sense. In a similar vein, Beavis (Chap. 7) argues that digital games are enabling high-level understandings to be gained. Beavis's chapter describes how digital tools expose students to sophisticated disciplinary and process knowledge, via tools that encourage engagement and fun—while exposing students to new forms of text and literacy.

Somewhat disturbingly, at least to us, some of these best design features of games are not being used to promote higher-order thinking and deep learning, but rather visually appealing drill-and-practice games. Although the reinforcement of facts and skills form a critical part of mathematics understanding, it is noteworthy that these are the type of game genre that are most likely to be introduced to classrooms. For example, in their work on the Mathletics software (3P Learning 2012), the designers adopted gaming principles and applied them to the learning of mathematics. The authors argue that the "material and relational organization of Mathletics play emerges over time through the entanglement of object design and ownership, the context and governance of use, and collaboration in play" (Nansen et al. 2012, p. 2) where the players can engage with either "maths-related activities and courses or play Live Mathletics" (p. 3). Such games are penetrating school classrooms and are increasingly used as revision and homework tools.

As new hardware and platforms become commonplace, software used on tablets and other mobile devices are likely to penetrate classroom learning environments. Two chapters of the manuscript are devoted to the use of apps in classrooms. As Larkin (Chap. 13) points out, the vast number of apps available to time-poor teachers is overwhelming (there are more than 500,000 'education' apps in the Apple iTunes store). He recognizes that this is problematic for teachers to be able to make informed decisions about suitability and relevance, unless they can spend considerable time actually engaging with the respective apps. In a detailed analysis of apps that report to promote mathematics learning, he identifies a large discrepancy in the quality of apps, with many of limited to no use at all in terms of mathematical learning. Nevertheless, he identifies some apps with huge potential for mathematics engagement. In his chapter, Calder (Chap. 12) maintains that the most useable learning apps allow individuals to pace their learning and self-select apps with more challenging concepts or processes. However, he reports that the nature and design of most apps lead to rapid familiarity and, consequently, disengagement. In many ways, most apps are at the opposite end of the spectrum to that of serious games—with the design sophisticated and potential for open-ended engagement similar to computer software of 30 years ago. Some popular entertainment apps have less functionality than some of the very first computer games (such as Space Invaders and Pacman). However, the relative low cost of most apps, and the fact that they can be used on increasingly popular tablet devices, ensure impact in and out of classrooms. Calder reports that the best function of apps is within an integrated program. The challenge in terms of eventual familiarity leading to relative disengagement is to keep the apps as part of a varied program, to ensure that they are relevant and appropriate for the students, and for the development of apps to be ongoing and responsive to critical review. He concludes that mathematics educators and students need to be influential in the development of apps, to especially ensure that mathematical thinking is given primacy. Such reasoning is constant throughout the manuscript, yet challenging given resources for entertainment games far exceeds that of games with an educational focus.

Mathematics and Digital Games in Other Learning Contexts

The mobile nature of digital games ensures that the lines between in-school and out-of-school gameplay is blurred. Thus, it is important to explore the possibilities of these games to create new spaces for learning and engaging with mathematics. From a social learning perspective, research has been concerned with the ways in which the games industry has been influencing 'interactive' learning via computers (Scanlon et al. 2005); creating spaces for students to create their own digital games in order to teach concepts to peers (Li 2010); or the ways in which the games are arranged to motivate learners to engage with the games (Habgood and Ainsworth 2011) and engage with higher-order problem solving abilities (Sun et al. 2011). These and many other studies seem to support the possibilities of digital games to promote learning.

The potential of the games environment to create dynamic visual imagery (Gros 2007) is a vast leap from the static pencil-and-paper tools of the classroom. Not only are spatial images important in terms of new forms of spatial reasoning, but the capacity to read such images is critical to success. Lowrie's (2002) work with Pokémon attests to this substantial leap in learning possibilities within mathematics

www.allitebooks.com

engagement and learning. The games environment creates many new possibilities for imagery that is beyond the scene as well as dynamic imagery—a far cry from the limited opportunities available in traditional teaching of mathematics. While there is some debate as to the value that games have in terms of the education environment, there is some sense that the inability for games to prosper and be valued in education is not because of the games per se but due to the conservative view of educationalists (Moreno-Ger et al. 2009). As Lowrie (Chap. 5) proposes, digital games appear to accommodate the visuospatial-reasoning skills required to interpret and manage information systems than traditional classroom practices and pedagogies. Digital games also allow gamers with different preferences and skills (or game profiles) to access and navigate the spatial demands of information.

Some studies have been more open-ended and have attempted to document the ways in which learners navigate through games and the strategies they used (Augustin et al. 2011; Bottino and Ott 2006). However, to explore the potential of games without an understanding of learner context and engagement is problematic. Squire (2006) has called for a much richer understanding of how identities are shaped through the games contexts and the impact of this engagement to wider social contexts. Indeed, there are dangers in taking a game that successfully engages learners in an out-of-school context and assuming it would be effective in classrooms. Avraamidou, Monaghan and Walker (Chap. 2) maintain it is necessary to:

> […] view mathematics as a cultural practice and doing mathematics as an artefact, person and sign mediated, object-oriented activity…. Taking non-school games, which are designed to be played for leisure, and trying to integrate them into a classroom setting, following a curriculum that expects school mathematics teaching and real-world rules, is a transition that needs further exploration and preparation on behalf of the students, teachers, curriculum developers and other education stakeholders.

Moreover, Jorgensen (Zevenbergen) (Chap. 6) highlights the fact that the social fabric of gameplay provides different levels of equity, access and preference. Since her work found that low socio-economic status students were reporting greater use of the digital games environment, and the potential for learning that can arise from these environments, she maintained that digital games could create new opportunities for constructing mathematical habitus for this group of learners. This is particularly important, as these students are most at risk of performing poorly in measures of mathematical learning.

Coda

Collectively, these 14 chapters explore the possibilities of the games environment to create new opportunities for learning for mathematics. The manuscript sought to examine a range of implications of the use of games to enhance and/or develop new mathematical understandings and dispositions. We have deliberately and intentionally sought authors whose work would disrupt current thinking of the potential for games to enhance (or not) mathematical learning. It was the intent to seek authors whose work could be theoretical or empirical but are always seeking to push boundaries in educational thought. Whether this disruption was around pedagogy, the technology per se, the potential for learning mathematics or issues associated with access and success, it was our intent to bring some of the leading thinkers and thoughts to what is potentially a new era in mathematics learning. The relative cost and pervasiveness of digital games in the modern world means that it is accessible to many—students, educators, policy makers and families. This makes it a potentially viable medium for learning and for the masses. But within this context, caution and limits need to be established as well. It is the case that the authors in this collection bring some of these debates and affordances into a forum for discussion. If this book achieves this, then we have attained our goal.

References

3P Learning. (2012). *Mathletics* [*Computer software*]. Sydney: 3P Learning Pty Ltd.

Augustin, T., Hockemeyer, C., Kickmeier-Rust, M., & Albert, D. (2011). Individualized skill assessment in digital learning games: Basic definitions and mathematical formalism. *Learning Technologies, 4*(2), 138–148.

Bottino, R. M., & Ott, M. (2006). Mind games, reasoning skills, and the primary school curriculum: Hints from a field experiment. *Learning, Media & Technology, 31*(4), 359–375.

Gee, J. P. (2003). *What videogames have to teach us about learning and literacy*. New York: Palgrave Macmillan.

Gros, B. (2007). Digital games in education: The design of games-based learning environments. *Journal of Research on Technology in Education, 40*(1), 23–38.

Habgood, M. P. J., & Ainsworth, S. E. (2011). Motivating children to learn effectively: Exploring the value of intrinsic integration in educational games. *Journal of the Learning Sciences, 20*(2), 169–206.

Li, Q. (2010). Digital game building: Learning in a participatory culture. *Educational Researcher, 52*(4), 427–443.

Lowrie, T. (2002). The influence of visual and spatial reasoning in interpreting simulated 3D worlds. *International Journal of Computers for Mathematical Learning, 7*(3), 301–318.

Moreno-Ger, P., Burgos, D., & Torrente, J. (2009). Digital games in eLearning environments: Current uses and emerging trends. *Simulations & Gaming, 40*(5), 669–687.

Nansen, B., Chakraborty, K., Gibbs, L., Vetere, F., & MacDougall, C. (2012). 'You do the math': Mathletics and the play of online learning. *New Media and Society, 0*(0), 1–20.

Scanlon, M., Buckingham, D., & Burn, A. (2005). Motivating maths? Digital games and mathematical learning. *Technology, Pedagogy and Education, 14*(1), 127–139.

Schoenfeld, A. H. (2010). *How we think: A theory of goal-oriented decision making and its educational applications*. New York: Routledge.

Squire, K. (2006). From content to context: Videogames as designed experience. *Educational Researcher, 35*(8), 19–29.

Sun, C.-T., Wang, D.-Y., & Chan, H.-L. (2011). How digital scaffolds in games direct problem-solving behaviors. *Computers & Education, 57*(3), 2118–2125.

Warschauer, M. (2007). The paradoxical future of digital learning. *Learning Inquiry, 1*(1), 41–49.

Wouters, P., van Nimwegen, C., van Oostendorp, H., & van der Spek, E. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology*. doi:10.1037/a0031311.

Robyn Jorgensen (Zevenbergen) is a Professor of Education: Equity and Pedagogy at the University of Canberra. Her work has been focused on issues of equity and access in relation to mathematics education. This work has sought to understand the ways in which mathematics practices are implicated in the success (or not) of students who have been traditionally marginalised in the study of school mathematics. Her work usually draws on the theoretical frameworks offered by French sociologist, Pierre Bourdieu, to better understand the ways in which practices within the field of mathematics education are implicated in the (re)production of equity and inequities.

Tom Lowrie is a Centenary Professor at the University of Canberra. Tom has an established international research profile in the discipline area of mathematics education and he has attracted considerable nationally competitive funding from the Australian Research Council. A substantial body of Tom's research is associated with spatial sense, particularly students' use of spatial skills and visual imagery to solve mathematics problems. He also investigates the role and nature of graphics in mathematics assessment. Tom has investigated the extent to which digital technologies impact on the education community including teachers, children, and their parents, as well as children's engagement in out-of-school settings. A particular focus of Tom's work has been on disadvantaged students (particularly Indigenous students and students living in remote areas). He was selected to publish an entry on rural and remote mathematics education in the Springer *Encyclopedia of Mathematics Education* (2014) and is co-author of the book, *Mathematics for Children: Challenging Children to Think Mathematically* (the most widely distributed undergraduate mathematics book in Australia and published in its fourth edition in 2012 by Pearson Australia).

Mathematics and Non-School Gameplay

Antri Avraamidou, John Monaghan and Aisha Walker

Abstract This chapter investigates the mathematics in the gameplay of three popular games (Angry Birds, Plants vs. Zombies and The Sims) that are unlikely to be played in mathematics lessons. The three games are different but each has been observed to provide opportunity for mathematical activity in gameplay. After describing each game, and the mathematics that can arise in gameplay, the chapter explores two questions: What kind of mathematics is afforded in these games? Can these games be used in/for school mathematics? Issues considered under the first question include: the nature of mathematics and the difficulty of isolating the mathematics in non-school gameplay; players' strategic actions as mathematical actions; and 'truth' and its warrants in different mathematical worlds. Issues considered under the second question include: tensions between curricular expectations and the mathematics that arise in gameplay; and possible changes in gameplay when a game is moved from a leisure to an educational setting.

Keywords mathematics/Mathematics · Non-school gameplay · Strategies · Abstraction-in-context · Theory of didactical situation · Three worlds of mathematics

Introduction

Gameplay can be used to present and structure mathematical activities in classrooms: Nim, for example, has been used extensively in French primary mathematics lessons (see Brousseau 1997); in England teachers have used the Shell Centre

A. Avraamidou (✉)
School of Education, University of Leeds, Leeds, UK
e-mail: antri.av@gmail.com

J. Monaghan
Department of Mathematical Sciences, Faculty of Engineering and Science,
University of Agder, Kristiansand, Norway
e-mail: john.monaghan@uia.no

A. Walker
School of Education, University of Leeds, Leeds, UK
e-mail: S.A.Walker@education.leeds.ac.uk

© Springer Science+Business Media Dordrecht 2015
T. Lowrie, R. Jorgensen (Zevenbergen) (eds.), *Digital Games and Mathematics Learning,*
Mathematics Education in the Digital Era 4, DOI 10.1007/978-94-017-9517-3_2

(1987–1989) *Design a Board Game* resource box in their lessons; in North America, the National Council of Teachers of Mathematics [NCTM] (2004) claim that mathematical games “can foster mathematical communication…can motivate students and engage them in thinking about and applying concepts and skills” <http://www.nctm.org/fractiontrack/>. Research, however, reminds us that learning mathematics through gameplay is not automatic: “games can be used to teach a variety of content in a variety of instructional settings…there is no guarantee that every game will be effective” (Bright et al. 1985, p. 133); “it appears that assumptions that students will see the usefulness of mathematics games in classrooms are problematic” (Bragg 2006, p. 233). However, these examples focus on mathematical games used in classroom settings which leaves a question about games that are not deemed appropriate for classrooms.

By a *non-school game* we mean a game that is unlikely to be offered for students to play in a mathematics lesson. It has been argued that non-school games can have beneficial impact on players’ problems solving skills (Chuang and Chen 2009) and spatial ability (Dye et al. 2009); and Gee and Hayes (2010) claim that some games require a considerable knowledge of geometry. The adoption of non-school games in a classroom largely depends on the classroom teacher (Bakar et al. 2006). When a digital game is used in a mathematics lesson, it is likely that the game meets a teacher’s interpretation of a curriculum objective (NCTM 2004). When a student chooses to play a new non-school game, they are highly unlikely to play this for reasons that a teacher might have in introducing the game in a lesson, such as curriculum content. Studies have shown that the content of non-school games is often irrelevant or not aligned with that of school curricula (Egenfeldt-Nielsen 2005). Further to this, students do not necessarily appreciate it when non-school games are used for education rather than fun (Bourgonjon et al. 2010). The issue of mathematics and non-school gameplay is, thus, far from straightforward. We restrict our attention, unless otherwise stated, to digital games, and all references below to *game* or *gameplay* may be assumed to concern digital games.

This chapter investigates the question: What mathematics is there in non-school gameplay[1]? How one understands and addresses such a question depends, amongst other factors, on one’s theoretical framework. Our framework is sociocultural in as much as we view mathematics as a cultural practice and doing mathematics as an artefact, person and sign mediated, object-oriented activity. From this position, our understanding of the question is that mathematics resides in mathematical activity and the answer to the question depends on the game, the player and the context of the gameplay.

To address the question, we focus on three popular (circa 2013) games: Angry Birds, Plants vs. Zombies and games in The Sims series. The next section presents these games and discusses mathematics that can arise in gameplay. This is followed by a discussion of two further questions arising from our considerations of the three games: What kind of mathematics is afforded in gameplay? Can these games be used in/for school mathematics?

[1] Note that we use the word *gameplay* and not *games* in this question. This reflects an ontological assumption that mathematics, if it exists at all, does not reside in the game itself but in the gameplay.

Three Games

We focus closely on three games, rather than surveying a large number, because of a conviction that the detail of gameplay is important in a consideration of mathematics in gameplay. We chose the three games below because: they are clearly non-school games; they have each given rise to observed gameplay which can, in a sense to be discussed in this chapter, be viewed as mathematical activity; there are differences in the nature of the mathematical activity in these three games; and they are popular games. For each game, we first describe the game and then raise issues concerned with mathematics.

Angry Birds

Angry Birds is a *casual game* developed by Rovio Entertainment which was first issued for the Apple iPhone and is now available for a range of iOS and Android devices, including high-definition versions for tablet devices such as the Apple iPad. An underpinning principle of casual games is that they can be played in very small blocks of time such as a 10-min bus journey (although some players may devote more time to the game). Typically, each level takes a short time to complete. Angry Birds begins with the narrative premise that the pigs stole eggs from the birds. The birds are consequently angry and take revenge on the pigs by firing themselves from catapults to destroy the pigs and their shelters. The task of the player is to aim the catapult to fire the birds at the pigs. As the game progresses, the shelters in which the pigs take refuge become increasingly complex and incorporate a wider variety of materials which present different constraints (for example, stone is more difficult to destroy than wood). In addition the structures often require a chain of actions so that the bird cannot be fired directly at the target but needs to hit, for example, a boulder which will strike a pedestal at the bottom of a structure and knock away support for higher levels. The birds also change as the game progresses with new attributes triggered by swiping the screen during the flight. A small blue bird, for example, splits into three smaller birds each flying at a different height whereas a white bird drops an egg when the screen is swiped. The player cannot choose which bird to deploy but is presented with a fixed number, type and sequence for each level. In order to achieve successful destruction of a pig, the player has to think about the nature of the structure and which part of the structure to target. The player then has to consider the flight path curve that the bird needs to take and so the angle at which the catapult must be pulled back in order to achieve the required trajectory. In addition, the further the catapult is pulled, the further the bird will travel, although speed is constant (whereas in real life, the further the catapult is drawn back, the greater the speed of the projectile/bird). The game draws the flight path for the current bird as it travels and the player can use this as a guide when launching the next bird.

In the following two subsections we recount two instances of individuals playing Angry Birds. The first arose from a chance encounter with a young person playing it. The second was an attempt to replicate the first encounter with a very different person, a mature mathematician. In both cases the (same) observer simply made notes on the gameplay.

Emily Plays Angry Birds

Emily is 4 years old. Her older sister has an iPod Touch so Emily is familiar with touchscreen games, although she is not often allowed (by her sister) to play them. She is familiar with the Angry Birds concept but has not previously played the game. She is excited to be playing games on an iPad. It is briefly explained to Emily that she needs to fire birds from the catapult to hit the pigs but she is given no direction about how best to achieve pig destruction. Emily fires a bird but the flight path is too low so the bird hits the ground before it reaches the pigs' shelter. When asked what happened, Emily says "I needed to go upper". The second shot is successful. Emily chooses higher levels to play and these require a strategic approach. Emily plans her attack by tracing the prospective flight path of the first bird. It might be expected that a 4-year-old would aim for the *easy* birds but Emily does not do this. Instead she aims the bird high, so that it will knock down the coping stones (Fig. 1) which fall behind the structure thus destroying two pigs. The bird falls forward and catches one pig.

It might be assumed that this was simply a lucky shot had Emily not carefully traced the arc before aiming the catapult. It should be noted that to an observer it seemed as though the shot would simply bounce off the structure and be wasted. However, Emily's reaction made clear that she had achieved the intended result. In order to plan the shot, Emily needed to consider how the blocks were arranged, the shapes of the blocks, the direction in which blocks would fall, the optimum point at which the bird should hit the structure and, finally, the flight path and the angle/distance at which the catapult should be released.

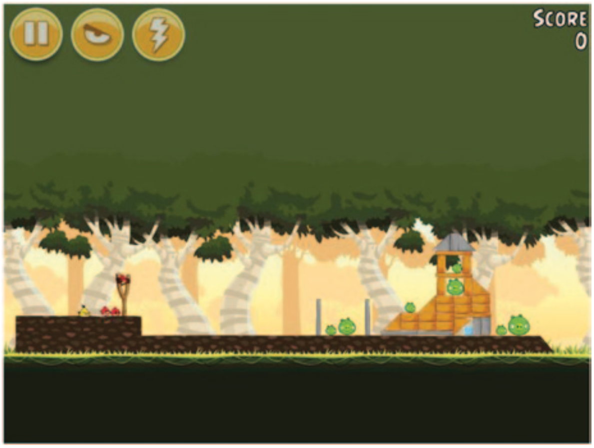


Fig. 1 Emily aims for the top

We believe that Emily's strategic thinking is mathematical (and we provide an argument that this is so in the Discussion section below); we also feel that Emily's strategic thinking is pretty impressive for a 4-year-old. Emily navigates this *mathematics* effortlessly but without analysis, which may be expected in a classroom. Her intention was to perform the necessary moves to destroy the pigs and she did this easily. However, she was not able to explain what she had done; she could give only simple description. Her lack of explicit knowledge of the mathematics is made clear by her inability to put in words the decisions that she has made.

Rich Plays Angry Birds

Rich is an adult, an academic in the field of mathematics education. Although a confident user of digital tools, Rich is not a player of electronic games and had not previously encountered Angry Birds. Rich takes aim and fires the first bird at the structure but the bird falls short. The same happens with the second bird. The third (of three) overshoots. Rich becomes frustrated with the game and gives up, saying, "As a mathematician and a scientist, this makes no sense to me". The problem for Rich is that although the game is mathematically accurate in some respects, for example, in terms of angles and curves, it does not completely replicate real-world physics. In real life, the further the catapult is drawn back the greater the speed of the projection of the bird. In Angry Birds, pulling the catapult back further increases the distance that the bird will travel but does not increase either the speed of projection or the force with which the bird strikes the structure. Rich is correct; in this respect the game makes no sense. Unlike Emily, he is able to explain the mathematics (and physics) of the game. However, Emily is able to use the mathematics within the game whereas Rich cannot.

The 'Magic Circle' and Mathematics

As with many games, the gameplay of Angry Birds takes place within a closed environment. Moore (2011) calls this the *magic circle* and relates it to the spaces in which traditional games are played, for example chessboards or card tables. Within the *magic circle* the rules of everyday life are suspended and replaced by the rules of the game. With traditional games the boundaries of the *magic circle* are clear and the rules are explicit; all players know how and when behaviours within the *magic circle* diverge from everyday life. Moore argues that the ubiquitous nature of digital gaming, especially on mobile devices, blurs the distinction between the *magic circle* and everyday life because the games do not have to be played in special places but are available everywhere. However the boundaries are blurred in other, perhaps more important ways. With traditional games it is obvious that the games operate in specialised contexts. For example, a game board clearly delineates the space in which the game is played and it is obvious to the players that the board is not real life. With Angry Birds there are aspects of the game which are clearly artificial such as the cartoon characters. There is no attempt to replicate reality with the birds and pigs, indeed, there seems to be a clear attempt to make sure that nobody could confuse them with real creatures as that could be distressing. The birds and pigs are clearly *magic circle* characters. However, the materials used in the structure are designed to look similar to real-world wood and stone and, to a certain extent, share the characteristics of their real-world counterparts. Wood is much easier to break than stone. The parabolas of the birds also appear to be real-world rather than *magic circle*.

The mathematics of Angry Birds is real and is explained clearly by Chartier (2012) and by teaching websites such as InThinking Teach Maths (2013). For example, InThinking Teach Maths provides resources for working with quadratic equations based on Angry Birds. Clearly, Rich is capable of understanding these equations where Emily is not. Yet Emily can play the game whereas Rich is puzzled by the mechanics. Because Emily does not yet have any real-world understanding of the mathematics employed in Angry Birds, she is able to enter the *magic circle* of Angry Birds completely and therefore can make the practical calculations that she needs to play the game successfully. In future years, when she reaches the curriculum stage that addresses the mathematics employed in Angry Birds she may be able to relate the skills she has developed inside the 'magic circle' to the abstract concepts of real-world mathematics.

Plants vs. Zombies

Plants vs. Zombies (PvZ) is another casual game: a *tower defence* real-time strategy game where you, the player, plant plants in your garden to repel zombies from entering your house (where they promptly eat your brains and you lose). There are a variety of plants and zombies with different defensive and attack attributes. The basic game has five levels: front garden by day/night; back garden by day/night; and roof. Each level has ten *adventures* (zombie attacks). Collecting suns allows plants to be planted. Successful planting strategies vary with the adventure as the zombies vary. In addition to the basic game, there are a variety of *puzzles*. We present the *last stand—roof* puzzle. Last stand puzzles have *onslaughts* (each with several *waves* of zombie attacks) and you successfully complete the puzzle when you have withstood five onslaughts.

Figure 2 shows the screen at the beginning of the puzzle (where plants are inserted into flower pots) of *last stand—roof* with the *plants* available to use (and their individual costs, measured in *suns*) displayed on the left and zombies (who will start their attack after the *set up*) in the inset. Going down from the top: plants 2, 3, 4, 5 and 8 are attacking plants (plants 2 and 4; 4 is an upgrade of plant 3, which also slow zombies down); plants 6 and 7 are defensive plants ('tall nuts' and 'umbrella leaves'); plant 1 is actually a plant pot (only needed on roof levels as there is no soil as there is in garden levels). To the right of the plant pot are the available suns (in *last stand* puzzles, most of the suns available during an adventure are available at the outset). The zombies (not present at this stage in this game) come in *waves*,

Fig. 2 The start of *last stand—roof*

Fig. 3 A possible configuration of plants in *last stand—roof*

mainly from the right hand side of the screen; the exceptions to this are *bungee jumping* zombies who can *land* zombies to, or steal plants from, the left hand side of the screen. Once an onslaught has been successfully defended, the player gets an additional 500 suns.

Figure 3 shows a possible configuration of plants and the start of the first wave of zombies. It is not a particularly good configuration but serves initial explanatory purposes at this point in this section. Rows (of 5) of plants 2, 3 and 7 have been planted. The cost of these rows is $5 \times 100 + 5 \times 300 + 5 \times 125 = 2675$ (suns) and

www.allitebooks.com

Fig. 4 Missing plants in *last stand—roof*

there are 5000−2675=2375 suns remaining. Note that the player does not need to do this arithmetic her/himself as once a plant is planted (or a wave withstood), the cost is automatically deducted from (or added to) the available suns. But although this automatic update of available suns means that mental or pencil-and-paper calculations are not necessary, the player must do some serious estimates because the initial 5000 suns (with additional suns after withstanding waves of zombies) is not generous—surviving until the end of the puzzle is just possible with careful use of plants/suns.

A problem with the configuration shown in Fig. 3 is apparent if we compare it with Fig. 4, which shows what happens in the Fig. 3 situation after a couple of minutes. There are missing plants. Some of the plants have been stolen by bungee jumping zombies, some have been destroyed by catapult zombies (the ones in little golf carts), and it can be seen that some are being eaten by zombies. These plants can be replaced but they cost suns, and it is not possible to survive for long with this configuration. Survival requires more strategic planning using powerful attacking plants (plants 3 and 4), the occasional chilli pepper (which clears a line of zombies but can only be used once) and, crucially, strategically positioned 'umbrella leaves'.

For reasons of space we skip to an initial configuration (Fig. 5) from which it is possible to survive the final wave of zombies.

We say *initial* because there is more to come but we need to wait until we have more suns from surviving waves of zombies. There are two spatial strategies behind the configuration in Fig. 5. The first is simply that we have positioned the plants in the first three rows, that is, we have kept them as far to the left as possible so that the zombies have to cover a lot of open ground (and they can be picked off in this open ground, at least in the first wave). The second is the use of umbrella plants to

Fig. 5 A possible winning initial configuration of plants in *last stand—roof*

protect the other plants from bungee jumping and catapult zombies; an umbrella plant (marked by U) in Fig. 6, will protect plants in all the other squares in the grid (so all the plants shown in Fig. 5 are safe).

Figure 7 shows an update of Fig. 5 that has a ‘tall nut’ at the right end of each row. This is needed in the second level since *pogo zombies* (see the top line of Fig. 7) travel fast but are brought to a halt by tall nuts. Notice that the two spatial strategies referred to above are used in this update: the plants are kept as far to the left as possible; an extra umbrella plant has been used to protect the central tall nuts.

Figure 8 shows the configuration moments before the successful end of the puzzle with just three zombies left. Extra tall nuts and umbrella plants have been used and a plant pot, which held a chilli pepper, has been destroyed by the dying large zombie in line 2.

Fig. 6 Positioning umbrella plants

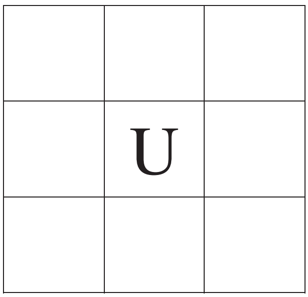


Fig. 7 An update of Fig. 5 that has a tall nut at the right end of each row

Fig. 8 The configuration moments before the successful end of the puzzle

Comment on the Mathematics

We comment on mathematical content in this puzzle and then consider the puzzle in terms of Brousseau's (1997) Theory of Didactical Situations (TDS).

Two areas of mathematics are *visible*, "easily recognisable mathematical operations" (Pozzi et al. 1998, p. 107), in this puzzle: estimation and spatial reasoning. Estimation is valued by people who write mathematics curricula. For example, in England, for students aged 11–14, *estimate* is listed in *key processes* under "use appropriate mathematical procedures" (Qualifications and Curriculum Authority [QCA] 2007, p. 143), and *estimate* occurs in three *attainment targets*: number and algebra; geometry and measures; and handling data. In this puzzle, whole number estimation using addition, subtraction and multiplication are useful and arguably essential to complete the puzzle. We also value estimation and view it as an important everyday life skill. Estimation is sometimes taught as a *one off* topic (a lesson on a specific form of estimation followed by a lot of lessons where estimation does not feature). This can be viewed negatively in that there is an argument that estimation should feature in mathematics classrooms "for a short period of time but often", to reinforce the use of this key process. For children in classrooms where estimation is not a regular part of their mathematical diet, the estimation used out of the classroom in this puzzle can be viewed positively.

We have commented on the use of two spatial strategies in this puzzle: keeping the plants as far to the left as possible; and using umbrella plants to protect the other plants. We consider the second of these strategies as it appears to us to be more clearly *visible mathematics* than the first strategy. We consider some of the subtlety of spatial reasoning involved.

a. We illustrated the strategy with a grid but we imposed that grid on the situation. The grid is *sort of* there in terms of the rows and lines demarking the tiles on the roof but it still requires an act of (geometric) mathematisation to view this in term of a grid.
b. If the rows and lines of the roof were multiples of 3, then the positioning of umbrella plants would be relatively straightforward—and you would use (number of rows/3) × (number of lines/3) umbrella plants. But the rows and lines (in use at a given stage in the puzzle) are often not multiples of 3 and this adds a layer of complexity to the spatial reasoning required.

It is interesting to note that although this spatial reasoning is *visible mathematics* to us, it is not *curriculum mathematics* in the above mentioned document (QCA 2007). There, under the heading Geometry and Measures, we get a list, "a) properties of 2D and 3D shapes…h) perimeters, areas, surface areas and volumes" (QCA 2007, p. 146). We return to considerations of visible, desired and actual mathematics in the Discussion section following the presentation of our three games. We now turn to TDS.

TDS is a well-respected theory of mathematics learning and instruction. We do not have space to describe it in its entirety but a central feature is three interrelated *situations*: of action; of formulation; and of validation. The situation of action involves *play* or trying things out. In this PvZ puzzle, the player must start by planting some plants. It is unlikely that s/he will be successful in the first (or second or…) attempt but the feedback from unsuccessful attempts may/will, iteratively, help the player to *start to model* the situation, e.g., I can only use so many of plant

X (estimation), I need to put an umbrella plant down to protect those plants… Over time/play the *start to model* bits build up into an explicit model and so begins a situation of formulation, a complete (but not necessarily correct) strategy for solving the puzzle (or mathematics task if this was in a mathematics classroom). Figure 5 shows a plant configuration following a situation of formulation.

The third of Brousseau's situations is that of validation which, in mathematics, concerns conviction, argumentation (explicit reasons why a strategy is correct) and, ultimately, proof. The situation of validation is of prime importance to professional mathematicians. It is hopefully present in many mathematics classrooms, but is there (or could there be) a situation of validation in the *last stand—roof* level puzzle? It is not easy to see how there could be other than in the sense of "I won, so my strategy was valid". We return to this in the Discussion section.

The Sims

The Series and its Modes

The Sims is a simulation game series where the player controls the lives of the game's characters (The Sims), builds and edits their houses and neighbourhoods, and watches his/her Sims as they evolve every Sims day. Unlike many popular games, The Sims player does not have an explicit goal imposed by the game nor does s/he compete with other players (or the computer) in order to win. S/he can set his/her own goals as s/he plays with The Sims and what is a *success* or a *failure* is up to the player to determine. Although The Sims series comes with a variety of extension DVD-ROM games that can be added to the initial game, there are three main game modes when playing The Sims (initial game): the Live Mode; the Buy Mode; and the Build Mode. The player can choose to play with a specific household, control the family's lives and watch them growing up (Live Mode) or might choose to pause the game's timer and edit the town by building or editing houses for The Sims or others (Build and Buy modes). The player can also create Sims characters from scratch and merge or divide households. We shall now describe in more detail the Build and Buy modes that we will use to discuss The Sims and mathematics.

The player can enter the Build and Buy modes when s/he pauses the game and selects the *Edit Town* option from the menu. Then a grid appears on the area being edited. The game has its own currency system (*Simoleons*) and each family/household has a certain budget that allows the player to build/buy goods for his/her Sims families (Fig. 9). This budget can be increased/decreased during the Live Mode if The Sims earn/spend money. Sims houses are built in empty plots and the player chooses whether to buy or build a house for a specific family. If the player buys an empty plot, then the process of building that house is limited by the family's budget. This is an important aspect of the game, because it narrows the player's actions to what the family can afford to buy. On the other hand, if the player starts building a house without being bought by a specific family, then there are no budget constraints. There is not a single path for a player to follow in order to build a house in The Sims. The only limitation this game has is that the player can choose whatever

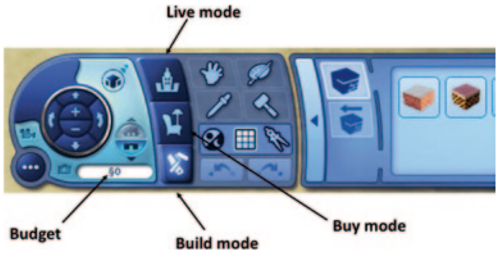


Fig. 9 The Sims' Live, Build and Buy modes menu

is provided by the game and when building a house for a family, s/he needs to build within the family's budget. The player can drag and drop items in his/her building usually starting with the foundations, tiles, walls, roof, swimming pool and other items from the Build menu and also add furniture, electrical appliances, trees and decorative items from the Buy menu (Fig. 9).

Examples from Children's Gameplay

How is mathematics related to The Sims series? Other than calculations that a player makes in order to manage a family's budget, the mathematics involved in The Sims series is often not *visible*. In order to examine invisible mathematics in the process of building houses we refer to Costas, an 11-year-old Cypriot boy playing The Sims 2 (see Avraamidou et al. 2012[2]) and George and Maria who were collaboratively playing, and building houses, in The Sims 3. Costas' and George-Maria's gameplay were recorded (both discourse and activity) using screen recording software with a researcher observing their activity without interfering with their gameplay.

Costas and George-Maria both started building houses without budget constraints and then built a house with budget constraints. Their building strategies changed as they noticed that the family's money was going down and they made considerable adjustments to the house's size (smaller) in order to be within the family's budget. The following two examples are provided in order to demonstrate the way these children reached a decision to add something in a budget-constrained house, when the budget was quite low.

Costas wanted to create doors for the living room and for the master bedroom's veranda. He wanted to add suitable doors so that the family would be able to have a swimming pool view. The glass-doors that could be used and could meet the requirements cost 350 *Simoleons*. Costas said:

> What? 350 pounds for the door (glass-door)? Oh!…that's expensive…well…there are more expensive ones, but…there are also cheaper ones…but, I want them [the family] to see the pool from the living room. Well, it's three doors for the lower floor and one for the master bedroom upstairs…That's up to 1500 pounds [he sighs]. I guess it's OK!

[2] The interested reader should see this paper for details on the research methodology, which produced the interpretations on which we report in this chapter.

Fig. 10 George and Maria's house with budget constraints

In a similar situation, George and Maria had finished building the house and started adding furniture. They bought a table, four chairs, a fridge, a bench, two beds, a sofa and a few light chandeliers and lights. By that time the family was left with only 127 *Simoleons* to spend. When they tried to add a toilet and a shower in the bathroom, most of the items in the Build and Buy menus were marked with a red colour because the family's budget was not enough (Fig. 10). So Maria said:

> We don't have enough money to get a toilet or a shower! How are they going to clean themselves? They can't live without a toilet! We need to make the house smaller. We haven't even put an oven yet in the kitchen. How will they cook?

George continued:

> They don't have a TV…nothing. We need to make the bedrooms smaller.

George and Maria estimated that they would need at least 2000 *Simoleons* to add the necessary furniture and started deleting foundations and walls in order to get the desired refund.

In order to reach their decisions in the above examples, both Costas and George-Maria used their everyday experiences and knowledge by taking into consideration the virtual Sims family's needs and a house's typical contents, but they also used their mathematics knowledge to make estimations and calculations within The Sims environment.

We shall consider Costas' gameplay in more detail to show Costas producing a mathematical abstraction while he was trying to place a door in the *middle* of the wall, the foundations in the middle of the plot area, and the swimming pool in the

Fig. 11 Costas' first house

middle of the side wall. We view his actions in terms of Hershkowitz et al.'s (2001) RBC model that regards abstraction in context as a process involving three nested epistemic actions: *Recognizing* a previously constructed structure; *Building-with* by combing earlier structures in order to achieve a goal such as solving a problem; and *Constructing* which refers to putting together artefacts in order to construct a new structure.

Placing the Door in the Middle of the Front Wall

When Costas was trying to place the door of the first house in the middle of the front wall (Fig. 11), he noticed that:

> C (Costas): Ah! The door takes 2 squares (in length) and the house is 15. I can't put it in the middle […] I think I will delete a column and in this way there will be 14 squares […] Since there are 14 squares now…then the door must be put after the 7th. One, two, three, four, five, six, seven…I think this is the place, it looks in the middle.

At a first glance, it seems that Costas simply divided 14/2 = 7, and placed the door on the 7th and 8th square of the wall but Costas did more than that. He recognised that in order to place a door that was 2 squares in length in the middle of a wall, the wall had to be an even number in length. This was the first step towards a strategy (which, we will argue in the following pages, is an abstraction) to design around the *middle* of a wall.

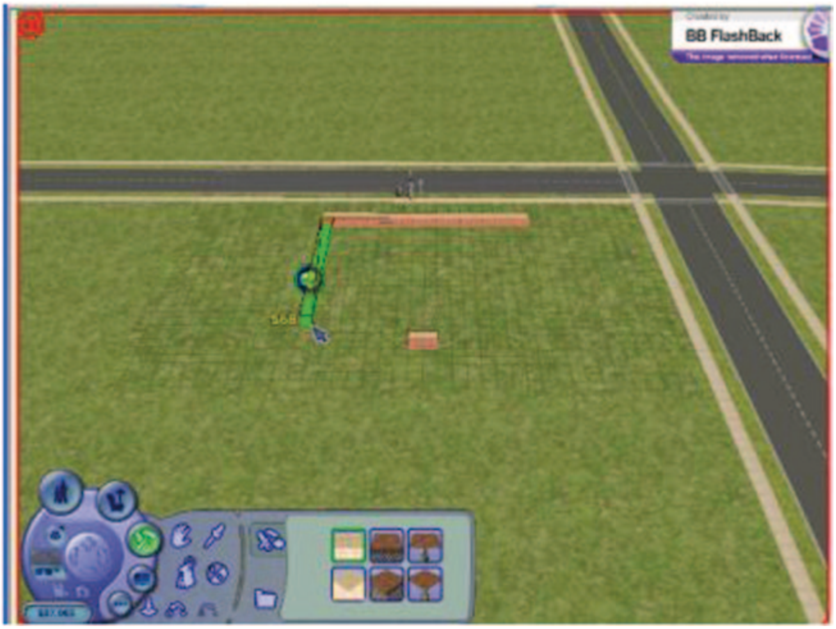


Fig. 12 Costas' third house—2-square point of reference

Building the Foundations in the Middle of the Plot (with Budget Constraints)

In building the second house (with budget constraints) he realised that when he created something, money was subtracted from the family's account. He also realised that when he deleted something that he had built, he did not get a full refund. For example, when he deleted a 1-squared wall that he had paid 70 *Simoleons* for, he only received a 56 *Simoleons* refund. Costas set himself a goal to create a house for a family with a swimming pool in the middle of the front of the house, making sure that the family will not lose (much) money because of the refund policy. In order to accomplish that, he created a 2-square 'point of reference' as described below.

When trying to place foundations of 18×18 squares in the middle of a 40×40 square plot during the building of his third house, Costas recalled the strategy that he had used when he wanted to place the door in the middle of the front entrance wall. So he counted 18 squares counting from the square that the family was standing on and then created a 2-square horizontal point of reference. He said: "the middle is the line between those 2 squares" (Fig. 12). He then added a row of 8 squares on the left of the 2-square point of reference and another row of 8 squares on the right side. This way he created a row of $8 + 2 + 8 = 18$ squares. He later added a vertical row of 18 squares as can be seen in Fig. 12 and then created the whole foundation of the house.

Fig. 13 Costas' third house—placing the swimming pool

Placing the Swimming Pool in the Middle of the House

Costas wanted to create the swimming pool in the middle of the left side of the third house and his plan was: "I think I will draw a line in the middle like I did with the squares [he meant the 2-square point of reference] before, and then start cutting from left and right". He counted the cubes starting from left to right until he reached the ninth cube and said: "the middle is the 9th and 10th cube together, because it's 18" (Fig. 13). He then painted them black, to see what to cut. He used the black squares as an outline of what he would cut in order to get the swimming pool in the middle of the foundation. Using this 2-square 'point of reference' strategy, Costas limited the refund issue that he had observed while he was building the second house, created a house of a desirable size and also saved money from the family's budget, which was his initial goal: to create a house for a family with a specific budget.

Those three extracts from Costas' gameplay imply that he recognised, constructed, used and reused a—suitable for him—strategy for placing a 2-square door in the 'middle' of the wall, creating the foundations of a house in the *middle* of the plot and placing the swimming pool in the *middle* of the left side of the house. Going back to Hershkowitz et al.'s (2001) RBC model, Costas recognised a situation where he could use a prior strategy, "I'll do the same as before", and used (built-with) his 2-square point of reference construction in order to accomplish goals and overcome difficulties that emerged in building his houses. When a similar situation occurred, he used the idea of having 2-squares as a *point of reference* as his way of locating the *middle* of the plot and the *middle* of the third house in order to place the swim-

www.allitebooks.com

ming pool. In terms of the RBC model, Costas' actions imply that there was an abstraction in context related to his understanding of the *middle*.

Discussion

The three non-school games above have similarities and differences. Angry Birds and PvZ were played as mobile/tablet apps but The Sims was played on a laptop. As previously mentioned, Angry Birds and PvZ are both casual games but The Sims is designed for a longer playing time and contains more modes, features and detail. Simply, the player can do more in The Sims than in the other games. However, all afford mathematics, in some form, in gameplay and some of this is (and some is not) visible in the sense of Pozzi et al. (1998). All afford counting, spatial reasoning and strategic thinking but there are differences in these processes in the games. In the remainder of this section we use the three games above to explore two important questions: What kind of mathematics is afforded in these games? Can these games be used in/for school mathematics?

'mathematics' and 'Mathematics'

In the section on PvZ we mentioned Brousseau's (1997) Theory of Didactical Situations (TDS) and noted that situations of action and of formulation were present in the account of PvZ, but that a situation of validation (which concerns argumentation and proof) was not, which begs the question: Is this mathematics? We now turn to considerations on the nature of mathematics in more general terms and with regard to all three games considered in this chapter. We structure our considerations under the themes *culture*, *strategy* and *truth* because these themes allow us to juxtapose ideas from mathematics and from gameplay: truth is central to the culture of mathematics but truth appears peripheral in gameplay; strategy[3] appears to be central in gameplay but strategy, though central in mathematical activity, is not, bar one specialist area of higher mathematics, a part of mathematics qua mathematics.

Culture can be viewed as "the accumulated artefacts of a group" (Cole 1996, p. 110[4]); the culture of mathematics, by this view, includes artefacts/tools such as 'valid' forms of reasoning, theorems and algorithms. A narrow interpretation of this standpoint leads to a view that mathematics is what professional mathematicians tell us it is. Bishop's study of mathematical enculturation located this narrow interpretation of mathematics as a central challenge to his study and he differentiated between *mathematics* and *Mathematics*:

> the mathematics which is exemplified by Kline's Mathematics in Western Culture is a particular variant of mathematics, developed through the ages by various societies. I shall characterise it as 'Mathematics' with a capital 'M'. (1988, p. 19)

---

[3] Strategy, as we shall shortly see, is a problematic term.

[4] Cole (1996) can be viewed as a 350-page explication of *culture*; these six words do not do justice to his considerations.

This view is also, arguably, present in Vygotsky's distinction between everyday and scientific concepts, as Scott et al. in writing of Vygotsky's distinction, note:

> scientific concepts are taken to be the products of specific scientific communities and constitute part of the disciplinary knowledge of that community…. As the agreed upon products of specific communities, scientific concepts are not open to 'discovery' by the individual but can only be learned through some form of tuition. (2011, p. 6)

Isolating Mathematics in non-school gameplay could consist of a mapping exercise from the actions in the gameplay to the accumulated artefacts that mathematicians regard as Mathematics. But there are problems in such a mapping exercise, the first of which we consider is that it may only capture mathematics which is *visible*. In PvZ, for example, calculating the suns remaining and positioning an umbrella plant for optimal protection may be recognised as Mathematical operations but, in The Sims, Costas' 2-square *point of reference* strategy is not a Mathematical operation, i.e., it is not recognised by the/a mathematical community. This creates a problem for us as we are convinced that this strategy is mathematical because, as argued in the section on The Sims above, Costas' strategy is a mathematical abstraction with regard to a specific theory of abstraction; we now turn to problems with this term *strategy*.

In the three sections above we characterise gameplay using words such as *strategy* and *strategic*. There is a curious everyday/scientific anomaly in our use of these words that we now consider. We three authors made a plan for this chapter but the first prose writing were the sections on the three games, each written by just one of us. When we compared the three sections we noted the use of these words and explored what they meant outside of our (consistent) *meaning in use*. *Strategy* is a scientific term in the *theory of games*:

> In the actual play of the game, each player…may formulate a complete plan for playing the game from beginning to end, for every situation that may arise. Such a plan is called a strategy. (Dresher 1961, p. 2)

and in warfare:

> In the terminology of war, strategy is understood as the analysis of the objectives to be achieved in the light of the total military situation, and the overall ways of accomplishing these objectives. (Guevara 1961/2006, p. 21)

These two definitions of strategy are similar: "a complete plan…for every situation that may arise"; "the overall ways of accomplishing these objectives". But these definitions do not capture Costas' or Emily's strategies: Costas and Emily are not playing against anyone; Costas' strategy is not present at the beginning, it emerges through gameplay; and Emily's *aim high* strategy is not a plan for every situation, it is specific to a game situation with a coping stone near and above a pig. Costas' and Emily's strategies are more like warfare's *tactics*; "tactics are the practical methods of achieving…strategic objectives" (Guevara 1961/2006, p. 25), though there is nothing specifically mathematical in Guevara's definition.

Web searches (various servers) using keywords *education*, *mathematics* and *strategy* convinced us that our use of these words was consistent with its use in practical and academic mathematics education literature. Here is another curiosity: the use of the term *strategy* in this field is often linked to Polya's (1945) *How to solve it*, but Polya does not use the term *strategy* in this book. *Strategy* in mathematics education literature makes reference to Polya's (1945) second (of four) steps in problem solving, devising a plan, and also to his heuristic, whose aim is "to study the methods and rules of discovery and invention" (Polya 1945, p. 112).

We conclude that there is some vagueness in educational discourse (including ours above) as to what the terms *strategy* and *strategic* mean. Nevertheless, we feel we can *tighten* this discourse, with reference to Guevara tactics and Polya's plan, and describe a mathematical strategy as an ordered sequence of actions on objects, which involve mathematical relationships (e.g., logical, arithmetical, spatial or other), intended to achieve a specific objective. The objects on which these actions are enacted do not need to be mathematical themselves; they can stand in place of mathematical objects, e.g., the squares in Costas' house are not mathematical objects but Costas' action on them are mathematical—"the door takes 2 squares". Indeed, most of Costas' strategic actions reported above are mathematical in this sense. Further to this, Emily's *aim high* strategy involved four objects: a bird, a catapult, a pig and a coping stone. The bird in the catapult can be positioned (the angle is the variable) to create a trajectory in which the bird hits the coping stone which is above the pig—Emily's strategy is mathematical by our description. We offer this description as a provisional definition in need of further consideration and move on to consider truth.

Truth in mathematics is established through forms of reasoning that are deemed logical, for example, *if A implies B, then not B implies not A* is logically true (*even numbers are divisible by 2, so numbers not divisible by 2 are not even*). In some games, mathematical forms of reasoning are *visible* in players' strategies, e.g., the form of reasoning "assume the opposite of what one posits and derive a contradiction and so determines the truth of the posited statement" (*reductio ad absurdum*) can be used in non-digital game Sudoku; when you know a cell must be either 4 or 5 but you do not know which and you assume it is 4 and follow this through to get a row or column with a disallowed repeated number, so you know that the number in the original cell is 5. It is reasoning in these logical forms (or, at least, approximations to these forms) that is sought in Brousseau's situations of validation. In gameplay, however, as in everyday life, the pervasive form of reasoning appears to be induction, generalising from observations/pattern recognition made in specific cases (see Nisbett et al. 1983). To explore this apparent impasse with respect to truth and forms of reasoning, we turn to Tall's (2004) three worlds of mathematics.

Tall is a research mathematician who turned to research in mathematics education. The impasse presented in the previous paragraph arose for him (though not in the context of gameplay) in his work in these two disciplines. He resolved this by positing three worlds of mathematics:

> The first grows out of our perceptions of the world and…our thinking about things…enable us to envisage conceptions that no longer exist in the world outside…[the second] is the world of symbols we use for calculation and manipulation in arithmetic, algebra, calculus…These begin with actions (such as pointing and counting) that are encapsulated as concepts by using symbols…The third world is based on properties…formal definitions that are used as axioms to specify mathematical structures…Other properties are then deduced by formal proof…new concepts can be defined and their properties deduced to build a coherent, logically deduced theory. (ibid., p. 285)

Truth in each of Tall's three worlds has different warrants:

> each world develops its own 'warrants for truth'…Initially something is 'true' in the embodied world because it is seen to be true…In arithmetic, something is 'true' because it can be calculated; in algebra, because one can carry out an appropriate symbolic manipulation…In the formal world, something is 'true' because it is either assumed as an axiom or definition, or because it can be proved from them by formal proof. (ibid., p. 287)

Tall's three worlds do not address the same partitioning of activity as the worlds of gameplay and of mathematics that we consider, but his three worlds interpretation does have implications for the *worlds* we consider in this chapter. Tall's three worlds note differences within what is viewed as visible mathematics; for example, a triangle, which is visibly mathematical, has three sides but how we view these three sides in each of Tall's world is different: look, there are three sides; (counting) 1, 2, 3; a triangle by definition has three rectilinear sides. The implication for gameplay is that we should not get too hung up on whether the mathematics in the gameplay is visible or not as there are major differences concerning the nature of mathematics within visible mathematics. Tall's first (respectively third) world has similarities with Bishop's *mathematics* (resp. *Mathematics*) and Vygotsky's *everyday* (resp. *scientific*) but where is Tall's second world with respect to Bishop's or Vygotsky's poles? Arguments can be put forward for placing it at either of Bishop's poles according to whether or not professional mathematics and school mathematics are viewed as similar or distinct domains of activity (see Chevallard 1988 for an argument that they are distinct). The implication for gameplay is that the pole divisions of mathematics/Mathematics and everyday/scientific may not be useful for considerations of mathematics in gameplay. Mathematics in gameplay, we feel, is situated in Tall's first or second world according to the gameplay; the first level of Tap the Frog (an app in which the player touches the frog on the screen when it appears) is certainly embodied (Tall's first world) but the strategic thinking in all three games we have considered is akin to Tall's second world where "*actions*… are encapsulated as concepts by using symbols" is translated as "actions…are encapsulated as concepts by using strategies" in the gameplay (using our provisional definition of *strategy* above). But the most important implication, for us, of Tall's three worlds for a consideration of mathematics in gameplay is his focus on different warrants for truth in the different worlds. The warrants for the third world (Mathematics) are rarely the warrants for gameplay and the focus of the "Is this mathematics?" argument becomes "Is this an acceptable warrant in a situation of validation?" It can be argued that Tall's three worlds, especially the third, may sometimes constitute 'magic circles' in themselves in that mathematics can include concepts that do not exist in the physical world (such as a line that has no width). Furthermore, when children play games, they may (as in Emily's case) operate in a mathematical world that they have not yet encountered in school. Views will differ but our view is summed up in a paraphrase of popular culture, "It's maths Jim, but not as we know it".

Can Non-School Games Be Utilised in School Mathematics?

Accepting that there is some form of mathematics in the gameplay of some non-school games does not necessarily mean that these games can be utilised in school mathematics. Non-school games are not designed for education and do not have educational objectives. Non-school games are designed for entertainment and are what Rieber (1996) characterises as exogenous games; their content, context and gameplay are inextricably linked. In all three non-school games that we described above, players used everyday knowledge in order to advance their gameplay. We have already argued that the mathematics used there was mostly 'invisible' and was integrated into the games' context. Trying to de-contextualise non-school game mathematics is fraught with problems. For example, "the middle of 18 is the line between the 9th and 10th square" statement of Costas or the "need to go upper" statement of Emily are unlikely to be valued in a classroom, though they make sense to Costas and Emily within their gameplay.

The gameplay of the same non-school game is often different and it is difficult to predict the course of the gameplay, which would create a problem for many teachers who value lesson plans and lesson objectives. Research by Bourgonjon et al. (2013) into teachers' acceptance of classroom use of non-school games revealed that even when teachers recognise learning opportunities offered by non-school games they are reluctant to use them in their teaching as there is no explicit connection to their lesson's objectives and gameplay can be time-consuming (see also, Sandford et al. 2006). All three games were played in the players' time and pace and, most importantly, outside a classroom. Further to this, students have certain expectations of mathematics lessons. Monaghan (2007), for example, reports on students undertaking a task set by a company director. The company director merely wanted a solution to the task but the students expected that they should use school mathematics. Thus, if Costas' or Emily's gameplay were taken into a mathematics classroom, their expectations and gameplay may differ.

A crucial question arises: how can non-school games be utilised in school Mathematics if the mathematics used in games is rarely related to school mathematics, the gameplay experience and strategies are often different among players, the teachers are not convinced that they should use them in their teaching, and not all students appreciate their usefulness in their learning? Perhaps this non-explicit connection to the lesson's objectives is related to the *invisibility* of mathematics used in non-school games discussed above. In addition, gameplay is sometimes dependent on the player successfully entering the *magic circle* and applying the rules of the game rather than *real-world* rules. When games are taken into a classroom there is a risk that by trying to make the mathematics explicit, the teacher may break the *magic circle*, making it difficult for learners to engage fully with the game. Taking non-school games, which are designed to be played for leisure, and trying to integrate them into a classroom setting, following a curriculum that expects school mathematics teaching and real-world rules, is a transition that needs further exploration and preparation on behalf of the students, teachers, curriculum developers and other education stakeholders.

References

Avraamidou, A., Monaghan, J., & Walker, A. (2012). Abstraction through game play. *Technology, Knowledge and Learning, 17*(1–2), 1–21.

Bakar, A., Inal, Y., & Cagiltay, K. (2006). Interaction patterns of children while playing computer games. In E. Pearson & P. Bohman (Eds.)*, Proceedings of the world conference on educational multimedia, hypermedia and telecommunications* (pp. 575–580). Chesapeake: AACE. http://www.editlib.org/p/23067.

Bishop, A. (1988). *Mathematical enculturation: A cultural perspective on mathematics education*. Dordrecht: Kluwer Academic Publishers.

Bourgonjon, J., Valcke, M., Soetaert, R., & Schellens, T. (2010). Students' perceptions about the use of video games in the classroom. *Computers & Education, 54*(4), 1145–1156.

Bourgonjon, J., De Grove, F., De Smet, C., Van Looy, J., Soetaert, R., & Valcke, M. (2013). Acceptance of game-based learning by secondary school teachers. *Computers & Education, 67,* 21–35

Bragg, L. (2006). Students' impressions of the value of games for the learning of mathematics. In J. Novotná, H. Moraová, M. Krátká, & N. Stehlíková (Eds.), *Proceedings of the 30th conference of the international group for the psychology of mathematics education* (Vol. 2, pp. 217–224). Prague: PME.

Bright, G. W., Harvey, J. G., & Wheeler, M. M. (1985). Learning and mathematics games. *Journal for Research in Mathematics Education, Monograph, 1,* i–189.

Brousseau, G. (1997). *Theory of didactical situations in Mathematics*. Dordrecht: Kluwer Academic Publishers.

Chartier, T. (2012). Frustrated with math? Try angry birds! *Huffington Post.* http://www.huffingtonpost.com/tim-chartier/frustrated-with-math-try-_b_1581042.html.

Chevallard, Y. (1988). On didactic transposition theory: Some introductory notes. Paper presented at the international symposium on research and development in Mathematics. Bratislava, Czechoslovakia.

Chuang, T. Y., & Chen, W. F. (2009). Effect of computer-based video games on children: An experimental study. *Educational Technology & Society, 12,* 1–10.

Cole, M. (1996). *Cultural psychology: A once and future discipline*. Cambridge: Harvard University Press.

Dresher, M. (1961). *Games of strategy: Theory and applications* (No. RAND/CB-149-1). Santa Monica: Rand Corp.

Dye, M. W. G., Green, C. S., & Bavelier, D. (2009). The development of attention skills in action video game players. *Neuropsychologia, 47*(8–9), 1780–1789.

Egenfeldt-Nielsen, S. (2005). Beyond edutainment: Exploring the educational potential of computer games (Unpublished doctoral dissertation). IT University, Copenhagen.

Gee, J. P., & Hayes, E. R. (2010). *Women and gaming: The Sims and 21st century learning*. New York: Palgrave Macmillan.

Guevara, E. (Che). (2006). *Guerilla warfare*. Melbourne: Ocean Press (Original work published 1961).

Hershkowitz, R., Schwarz, B., & Dreyfus, T. (2001). Abstraction in context: Epistemic actions. *Journal for Research in Mathematics Education, 32*(2), 195–222.

InThinking Teach Maths. (2013). Angry Birds 2. teach Mathematics: Lessons to look forward to. http://www.teachmaths-inthinking.co.uk/activities/angry-birds.htm.

Monaghan, J. (2007). Linking school mathematics to out-of-school mathematical activities: student interpretation of task, understandings and goals. *International Electronic Journal of Mathematics Education, 2*(2), 50–71. http://www.iejme.com.

Moore, C. (2011). The magic circle and the mobility of play. *Convergence: The International Journal of Research into New Media Technologies, 17*(4), 373–387.

National Council of Teachers of Mathematics [NCTM]. (2004). Communicating about mathematics using games. http://standards.nctm.org/document/eexamples/chap5/5.1/.

Nisbett, R., Krantz, D., Jepson, C., & Kunda, Z. (1983). The use of statistical heuristics in everyday inductive reasoning. *Psychological Review, 90,* 339–363.

Polya, G. (1945). *How to solve it*. Princeton: Princeton University Press.
Pozzi, S., Noss, R., & Hoyles, C. (1998). Tools in practice, mathematics in use. *Educational Studies in Mathematics, 36,* 105–122.
Qualifications and Curriculum Authority [QCA]. (2007). Programme of study for key stage 3 and attainment targets. London: Qualifications and Curriculum Authority, Crown Copyright.
Reiber, L. (1996). Seriously considering play: Designing interactive learning environments based on the blending of microworlds, simulations and games. *Education and Technology Research and Development, 44,* 42–58.
Sandford, R., Ulicsak, M., Facer, K., & Rudd, T. (2006). *Teaching with games: Using commercial off-the-shelf computer games in formal education.* Bristol: Futurelab.
Scott, P., Mortimer, E., & Ametller, J. (2011). Pedagogic link-making: A fundamental aspect of teaching and learning scientific conceptual knowledge. *Studies in Science Education, 47*(1), 3–36.
Shell Centre. (1987–1989). *Numeracy through problem solving: Design a board game, produce a quiz show, plan a trip, be a paper engineer, be a shrewd chooser*. London: Longman.
Tall, D. (2004). Thinking through three worlds of mathematics. *Proceedings of the 28th conference of the international group for the psychology of mathematics education* (Vol. 4, pp. 281–288). Bergen: PME.

Antri Avraamidou is a doctoral candidate at the University of Leeds in the area of Mathematics and ICT. She also works as a Research Associate in the Department of Educational Technology at Cyprus Pedagogical Institute and as a Lecturer in Educational Technology at the University of Nicosia. Her PhD study explores the emergence of mathematical meanings through collaborative gameplay of the commercial video game The Sims 3, in out-of-school settings. In addition, through Cyprus Pedagogical Institute's European Union-funded projects, Antri has expanded her level of research expertise on ICT and Education, in-service teacher ICT training, visualised learning design methodologies technology and the use of ePortfolio and eAssessment. She has published a number of journal articles on visualised learning design and gameplay.

John Monaghan is Professor of Mathematics Education at the University of Agder, Norway. Prior to this he was at the University of Leeds for 25 years and a school teacher for 10 years before that. John enjoys research and teaching (but not admin). His research interests are firmly centred in mathematics education and include learners' understanding of algebra and calculus, linking school and out-of-school mathematics, the use of technology in learning and in teaching. In his leisure time he is a keen gamer and has enjoyed bringing gaming into his professional interests in recent years. He retains his link with the University of Leeds through the supervision of doctoral students, one of which, Antri, is a co-author in a chapter in this book.

Aisha Walker is Associate Professor of Technology, Education and Learning at the University of Leeds where she is Programme Director of the MA Technology, Education and Learning. Her research areas include digitally-mediated communication, digital learning and children's engagement with digital technologies. She has published papers in journals such as the *Journal of Computer Assisted Learning, Education 3-13, Technology, Knowledge and Learning* and the *International Journal of Mobile and Blended Learning,* as well as chapters in a number of edited collections. Aisha is also co-author of *Technology Enhanced Language Learning: Connecting Theory and Practice* published by Oxford University Press (2013). More information is available at <http://www.education.leeds.ac.uk/people/academic/walker>.

Integration of Digital Games in Learning and E-Learning Environments: Connecting Experiences and Context

Begoña Gros

Abstract Researchers and educational practitioners are increasingly turning their attention towards the effects of the use of digital games for learning. Many games satisfy the basic requirements of learning environments and can support the teaching and learning process. However, an in-depth understanding is needed of the different possibilities that digital games can provide in order to successfully integrate educational methods and game design. The main goal of this chapter is to analyse how the use of digital games could be integrated into learning with special emphasis on the importance of games for connecting experiences, context and learning. The chapter starts with a description of the different terminology used in the field of game-based learning. Then, we provide a summary of the main results obtained by researchers regarding the potential of digital games to support learning and we analyse the main directions for using game-based learning.

Keywords Game-based learning · E-Learning · Gamification · Digital games · Serious games · Integration of digital games for learning · Effects of digital games in learning · Players

Introduction

The use of electronic games in education has experienced a significant evolution. Initially, electronic games were developed in the entertainment market without considering their impact on learning. However, since the 1980s several studies have identified the potential of games for learning (e.g., Gee 2003; Kafai and Ching 1996; Malone 1981; Prensky 2001; Squire 2002). The author's main argument is that some commercial video games, especially strategy games, simulations and role-playing games, are based on well-developed theories of learning in order to engage players and teach them how to play the game (Gee 2003). Many suggest that by situating players in these virtual worlds, where they can move and act freely,

B. Gros (✉)
Faculty of Education, University of Barcelona, Barcelona, Spain
e-mail: bgros@ub.edu

© Springer Science+Business Media Dordrecht 2015
T. Lowrie, R. Jorgensen (Zevenbergen) (eds.), *Digital Games and Mathematics Learning,* Mathematics Education in the Digital Era 4, DOI 10.1007/978-94-017-9517-3_3

the games can promote problem solving, goal-oriented behaviour, engagement and motivation (Prensky 2010; Shaffer et al. 2005). Others argue that games help to develop strategic thinking, group decision-making and higher cognitive skills (Arnseth 2006; Clark et al. 2014; de Freitas 2006). Some researchers claim that games permit constructive, situated and experiential learning, which is enhanced by active experimentation and immersion in the game (Squire 2008; Hainey et al. 2011). Generally, it seems that games could be particularly useful for generating a deeper understanding of complex settings (Gros 2007), mainly when dealing with multifaceted variables.

In spite of this potential, some studies also report problems with the use of digital games for learning (Egenfeldt-Nielsen 2006; Ferdig 2007). Among the most notable issues are the lack of acceptance of games as an educational tool, the problem of integration into formal schooling, the tension between gameplay and learning objectives, and the problem of transferring knowledge gained in video games to the real-world.

The findings of games studies are conflicting and even contradictory due to the broad nature of the studies. However, interest in this topic is increasing, thanks to the continuous expansion of this technology, not only in schools and colleges, but also in universities (New Media Consortium [NMC] 2012).

Researchers and educational practitioners are increasingly turning their attention towards different types of games, such as epistemic games, serious games, multiplayer games and social games. The growth of online gaming may also produce more learning experiences connecting learning at work, home and formal learning institutions.

The aim of this chapter is to analyse how the use of digital games could be integrated into learning with special emphasis on the importance of games for connecting experiences, context and learning. The chapter is divided into four sections. Firstly, we will establish a distinction between different concepts related to game-based learning. Secondly, we will summarise the main results obtained by researchers regarding the potential of digital games to support learning. Next we will describe some challenges to integrating digital games into e-learning and finally, we will analyse the main directions for using game-based learning.

From Video Games to Gamification

There is a rich vocabulary around the use of digital games. In this section, we discuss the main terminology to clarify the evolution of electronic games and the different types and applications.

The general label of ‘video game’ or ‘digital game’ can be applied to many different types of games. We can identify multiple genres or categories of computer games including, but not limited to, action games, adventure games, simulation games, sports games, strategic games, puzzle games and role-play games.

It is possible to categorise the games based on many factors such as method of gameplay, content, type of goals, style or interactivity. However, as technology continues to evolve, digital games have developed into ever more complex games which have enhanced some possibilities and have added new ways of playing and new types of platforms. Some genres are combinations of others. For instance, most sports games, like the FIFA Football series, contain information needed to manage a team and combine simulation with characteristics of strategy games. What is relevant is that most of the well-known games (with their constantly updated versions) contain features of simulation and adventure. Elsewhere, strategy is also present in most historical simulations, such as Age of Empire, Civilization, and Imperium. In other words, there is a tendency to produce games that provide complex environments in which content, skills and attitudes play an important role during the game.

The way to play has also changed. Most of the video games created in the last decade are played individually. However, video games are increasingly being designed for multiple players. We can distinguish among: *online games*, *massive multiplayer online games* (MMOGs) and *social games*.

Online games are video games played over a computer network (Rollings and Adams 2006). The expansion of online gaming is based on the overall expansion of computer networks and ranges from simple text-based environments to games incorporating graphics and virtual worlds populated by many players simultaneously.

MMOGs provide a common online platform that draws players together from all over the world and they have come to dominate the digital entertainment industry (Magnussen and Misfeldt 2004). These games are an evolution of games formerly known as Multi-User Dungeon or Domain or Dimension (MUDs) and are referred to as 'virtual worlds' as they are not simply games in the traditional rules-based sense, but rather open-ended narratives where players are largely free to do as they please. A central element in multiplayer games is that the interaction enables players to communicate and collaborate in the game sessions.

Recently we have also seen social games connected with specific social networks like Facebook. According to Revuelta and Bernabé (2012), not all social games are the same. Some video games use the social network only as a distribution medium. In other cases, the social network facilitates finding other players at a given time (e.g., poker games or UNO) and some games use the social network in the different layers of communication that this provides. The game can be played among the 'friends' who have accepted and, at the same time, globally among all network users. A good example of this type of game is Farmville. This game uses Facebook to offer something that would otherwise be truly unachievable in any other platform.

The production of games for mobile phones and tablets has also increased the social dimension. According to Klopfer, "mobile games allows the creation of flexible and ever-changing complex games, promotes the ability to adapt games to a number of different styles such as competition and collaboration, creates situations in which players learn specialised communication, and produces a social dynamic in which players need to construct arguments and strategies with and against other players" (2008, p. 38).

In many products—like Civilization, Zoo Tycoon, Rise of Nations and The Sims—models and simulations are an integral part of the game. In all these examples the game stresses first- and third-person player experiences. In some cases,

www.allitebooks.com

the whole game is a model of the practice and culture of the particular topic. For instance, in Tony Hawk's Pro Skater players can design their own skaters, clothes, boards, skate parks and so on. They build a mode and interact with a set of more abstract models of environments that help to build a more realistic context.

According to Van Eck (2006), there are three main approaches to creating games that provide cognitive growth for the gamer. These three approaches are: building games from scratch created by the educator, creating games from scratch by the students, and integrating commercial off-the-shelf (COTS) products.

The use of COTS games in the classroom means that teachers have to integrate commercial games. In this case, it requires teachers to have adequate self-efficacy concerning the use of these games and their technology. Most COTS do not have an educational goal. However, a number of successful uses of COTS in formal education settings have been documented (Ulicsak and Williamson 2010; Sandford et al. 2007). One example is Blunt's adoption of COTS management simulation video games (Industry Giant II, Zapitalism and Virtual U) for business studies (Blunt 2009). Other COTS games already being used in the classroom include Civilization (history), Age of Empires II (history), CSI (forensics and criminal justice), The Sims 2 (building complex social relationships), Rollercoaster Tycoon (engineering and business management), and SimCity 4 (civil engineering and government). For some of these, there is a clear match between the game's explicit content and the classroom subject; for others there is a match between the aims and skills involved in the course of study and the game's underlying strategies and gameplay (Sandford et al. 2007).

In recent years, there has been a resurgence of educational games due to the rise of the *serious games* movement. Michael and Chen consider serious games are those "in which education (in its various forms) is the primary goal, rather than entertainment" (2006, p. 16). These serious games may be differentiated from educational games because of their focus on the post-secondary market and training. This growing interest in serious games is also linked to economic considerations because companies need to instruct employees and individuals need to update or innovate their skills from a lifelong learning perspective. In addition, serious games are also entertaining and this should encourage people to spend their free time on educational activities. The production of serious games is especially important in the field of business/management, healthcare and military training.

Epistemic games are another interesting type of game designed primarily for training professional skills. The main goal of epistemic games (Shaffer and Gee 2006) is to help players learn to think like professionals. This concept is based on the idea of 'epistemic frames'—the way in which a profession or other community of practice thinks and works—and entails a situated and action-based form of learning built around the ways in which professionals develop these epistemic frames. Shaffer (2008) argues that this approach makes it possible to create epistemic games in which subjects learn to work as doctors, lawyers, architects, engineers, journalists and other valued professionals; in this way they develop the skills, habits and concepts of a post-industrial society. These games help them to develop ways of thinking and knowing that are valued in the world, giving them a way to imagine the future person they might someday become.

Game Based Learning (GBL) refers to the use of video games to support teaching and learning. "It encompasses the use of both games designed expressly for fulfilling learning objectives (educational games) and 'mainstream games'—i.e., those games that are developed for fun when used to pursue learning objectives" (Kirriemuir and McFarlane 2003, p. 19).

Due to the success of games used for learning, some didactical proposals are introducing the concept of gamification. Kapp describes gamification as "the careful and considered application of game thinking to solving problems and encouraging learning using all the elements of games that are appropriate" (2012, p. 12). The main idea is to use the mechanics and game-design techniques to enhance non-game scenarios (Zichermann and Cunningham 2011) to increase the learner's motivation and engagement. The idea is to introduce something normally used in a game, such as incentives, immediate feedback and rewards, into an online subject or into the classroom. For instance, in e-learning it is possible to introduce a specific quest with a gamified formative assessment. Game-based learning and gamification often overlap. In a gamified classroom, it is possible to use games throughout the unit or it is possible to create a gamified unit using a serious game. In summary, game-based learning can be a small component of the learning process or a descriptor of the entire pedagogical model. Gamification, on the other hand, refers to changing the entire model of instruction to be a game or game-like. In both cases the main goal is the same: student engagement. And, in both cases, there must be a paradigm shift in the educator from 'sage of the stage' to 'guide on the side' (King 1993). Regardless of which method or pedagogy is employed in the classroom, games provide an opportunity for students who may not have been fully engaged in learning to go on to achieve success.

The use of games has been shown to be successful for encouraging student participation and maintaining contribution. Developments in gamification, serious computer games, and game-based learning are becoming important for virtual learning environments (VLEs).

Foundation of Digital Games for Learning

In the 1980s, computer games were presented as a potential learning tool based on the idea that games improve learners' motivation. According to Ke (2009), most of the literature on the use of digital games was based on authors' opinions regarding the potential of instructional games or proposals about how games could be developed to be instructionally sound. During that period of time, few articles documented the effectiveness of instructional games, much of the work was descriptive (Dempsey et al. 1996) and the real use of games for learning was very scarce. However, in the last decade, the amount of research into game-based learning has increased considerably (Ke 2009; O'Neil et al. 2005; Hwang and Wu 2012;

Mayer 2012). Currently, we can find studies in a variety of learning settings: elementary education, secondary education, adult education, business management, military and healthcare. Some studies focus on general problem solving and skills development (Hwang and Wu 2012), and there are also an important number of studies based on the use of games in learning subject areas such as mathematics, language arts, reading, physics, health, natural sciences and science.

Despite the diversity and scope of the studies, this is still an area with considerable weaknesses. Mayer (2012) considers that there is an increase in publications, methods, tools and findings, but there is not a methodology for digital games research and most of the experiments are very short and do not provide longitudinal data. According to Hwang and Wu (2012), most research is mainly focused on the investigation of students' motivations, perceptions and attitudes toward digital games.

The central consideration supporting the use of digital games for learning is based on the idea that video games provide a good learning environment in accordance with the main principles of active learning (Gee 2003; Kafai and Ching 1996; Malone 1981; Prensky 2001; Squire 2008). Players have to understand the internal design and the social practice that determine the activity of the game. Along these lines, Gee (2003) has proposed 36 learning principles that provide a comprehensive account of the potential of games for creating engaging learning, problem solving skills, cooperation and practical participation. In summary, "games are powerful contexts for learning because they make it possible to create virtual worlds, and because acting in such worlds makes it possible to develop the situated understandings, effective social practices, powerful identity, shared values, and ways of thinking of important communities of practice" (Shaffer and Clinton 2006, p. 7).

Some studies intended to explore whether digital games play any role in supporting educational goals. The analysis of the available studies by subject matter reveals that some knowledge domains are particularly suited to gaming, such as mathematics, physics and language arts (Hays 2005; Ke 2009). Researchers also explore how game-based learning activities should be organised. For instance, Sandford et al. (2007) report that teachers' facilitation plays an important role in an effective use of instructional games in the classroom. These studies consider that the investigation into computer games for learning should focus on how games can be aligned with pedagogical strategies or learning conditions to be beneficial (Hwang and Wu 2012).

Few studies analyse the learner characteristics; only gender has been examined (Dempsey et al. 1996; Haynes 2000; Hays 2005). However, if the use of games can support personalised learning, it is important to analyse the profile of players/learners. Games should present players with challenges that are matched to their skill level in order to maximise engagement (Kiili 2005). A game has to be able to provide the opportunity for appropriate guidance or collaboration in order to help players meet the next challenge. "The key is to set the level of difficulty at the point where the learner needs to stretch a bit and can accomplish the task with moderate support" (Jalongo 2007, p. 401).

Generally, instructional computer games seem to facilitate motivation and engagement across different learner groups and learning situations. This finding is in agreement with Vogel et al.'s (2006) quantitative meta-analysis conclusion that the effect size of games versus traditional teaching methods is highly reliable for attitude outcomes. "Games contain the pieces necessary to engage students and help them enter a state of flow where they are fully immersed in their learning environment... and focused on the activity they are involved in" (McClarty et al. 2012, p. 14). When complete attention is devoted to the game, a player may lose track of time and not notice other distractions. Games support many of the components of flow (Csikszentmihalyi and Nakamura 1979) such as clear goals, direct and immediate feedback, balance between ability level and challenge, and sense of control. These components can increase student engagement, and student engagement is strongly associated with student achievement (Shute et al. 2009).

Another contribution offered by games is the support of problem solving activities. Some authors consider this contribution intrinsic to gameplay (Gee 2007; Kiili 2007; Hung and Van Eck 2010). However, some designers consider it important to establish dialogue and collaboration between instructional designers and game developers to gain a better idea of what types of gameplay will most appropriately afford given learning goals and objectives (Hung and Van Eck 2010). Similar efforts have been made with serious games by mapping identifiable steps or events in game interaction against general learning activity frameworks. One reference adopted for interpreting game pedagogy is Bloom's taxonomy and Gagné's nine events of instruction (Hung and Van Eck 2010).

Several studies have explored whether these games play a role in supporting current educational objectives. In most cases (de Freitas and Oliver 2006; Gros 2007; Gros and Garrido 2008; Sandford et al. 2006), the most common obstacle facing the use of digital games in schools is identified by the teachers and refers to some practical difficulties. They identify the use of the games as positive learning experiences, but mention a number of problems and limitations: the lack of time available to familiarise themselves with the game, the problem of selecting the game and the difficulty in persuading other colleagues of the benefits, and the lack of educational games to support the curriculum. Assisting teachers with game-based learning may therefore require more flexibility in terms of lesson duration, as well as measures to ensure adequate time for lesson preparation and good technical support. Teachers require guidelines and frameworks for supporting innovative practice, "achievement of educational objectives was more dependent upon a teacher's knowledge of the curriculum…than it was on their ability with the game" (Sandford et al. 2006, p. 3). In summary, the teacher played a central role in scaffolding and supporting students' learning.

The Use of Digital Games in E-Learning

Games can be used in traditional face-to-face classrooms, but there is also a very promising use of games in virtual learning environments. In this section, we describe some of the main challenges and problems of using digital games for e-learning.

E-learning can be used as a general term that includes all forms of educational technology in learning and teaching. However, in this case we use the term as the modality of asynchronous teaching and learning. E-learning describes education that occurs in a distance education mode using the web as the sole medium for all student learning and contact. The value of e-learning lies in its ability to train anyone, anytime, anywhere. E-learning or blended learning (the combination of face-to-face with virtual activities) must provide a complete environment to support students' learning processes.

Traditional models of e-learning have focused on content as the most important element of the courses. However, the evolution of technology is fundamental in the evolution of e-learning. Innovation in ICT is providing new ways to deliver online learning. E-learning can be viewed as "an innovative approach for delivering well-designed, learner-centred, interactive and facilitated learning environments to anyone, anyplace, anytime by utilising the attributes and resources of various digital technologies along with other forms of learning materials suited for open, flexible and distributed learning environments" (Khan 2005, p. 33).

Bates (2011) considers that e-learning allows the development of important skills for the knowledge society: skills related to the use of technology, independent study, searching for information, problem solving, collaborative learning, personalisation and lifelong learning. However, we can find a lot of games for e-learning based on a behaviourist approach of learning and mainly focused on the transmission of content and not on complex learning activities. In fact, there are many companies and some open software that provide templates to produce e-learning games based on training games, quizzes and polls.

Personalisation in e-learning is an important challenge that can be achieved by tapping into the interactive potential of games. The most obvious type of adaptation in video games is the inclusion of different levels of difficulty; trying to adjust the challenge to different levels of skill. However, the potential is even greater thanks to the high interactivity of games, which can be used to implement much more fine-grained adaptation mechanisms. Some advanced games can even carry out this adaptation transparently to the user. For example, the Left4Dead™ saga <http://www.valvesoftware.com/games/l4d2.html> includes an artificial intelligence engine that customises elements like pathways through the game world, enemy populations and also the game atmosphere and environment through adaptive music, sound and visual effects according to the player's style of play.

An important dimension of digital games is connecting the game worlds to real worlds, either by adopting advanced technologies or by building communities of practice. With proper technology and storylines, digital games could extend learning from the virtual game world to the real-world, providing students with more authentic experiences. Squire and Klopfer (2007) and Rosenbaum et al. (2006) illustrate examples of using augmented reality technology to explore the real-world through digital games.

The integration of video games or 3D immersive virtual worlds into e-learning is not new. However, implementing communication between the game and the virtual learning environment (VLE) is not always easy.

A VLE is an e-learning education system based on the web that provides a virtual space equivalent to classes. It contains the content of the course, homework, grades, assessments, social space where students and teacher can interact through threaded discussions, social tools and other external resources, such as website links.

In the last decade, there has been much debate about the benefits of using VLEs because it is difficult to create standards for integrating other resources developed outside the virtual learning environment. This is mainly the situation related to the use of digital games.

In order to use digital games for learning purposes, games and VLEs need to establish active and bidirectional communication to support the exchange of data. Current e-learning standards were not designed to support this kind of communication. Some standards address the communication between VLEs and content (e.g., Sharable Content Object Reference Model [SCORM]) or the adaptation of the learning flow, but we still need to deal with the current diversity of VLEs and with a lack of specific standardisation support for the peculiarities of game-based learning. According to Moreno-Ger et al. (2009), a game developer who wants to integrate a game into a VLE must identify which standard/specification will be used in the VLE to store the data and how the games will exchange information with the VLE. Given the current situation, with diverse standards available, this does not guarantee the full interoperability of the contents, leaving the investment unprotected.

The standardisation of learning games does not seem to be very systematically developed. Livingstone and Hollins (2010) report that various technical standards for gaming can be used, such as different standards in 3D technologies, browser languages and also different kinds of multimedia standards like Flash or, more recently, HTML5 for use with mobile devices. Interactive storytelling has a specific relevance to the design of learning games and the IMS-LD (International Management System-Learning Design) standard has been shown to have this potential.

Kelle et al. (2011b, p. 527) describe two design methodologies (Fig. 1), starting the design cycle from the gaming or the e-learning standards perspective.

By starting the design from the side of learning, it is possible to model the educational process and then iteratively integrate game elements into the instructional design. From the game perspective, the methodology links game elements with learning activities and outcomes. According to Kelle et al. (2011a), both models have limitations and the ideal situation would be to have both directions in one learning game.

Despite the fact that the standards implemented by VLEs are diverse, a small number of these are starting to dominate the market share (for instance, Moodle,

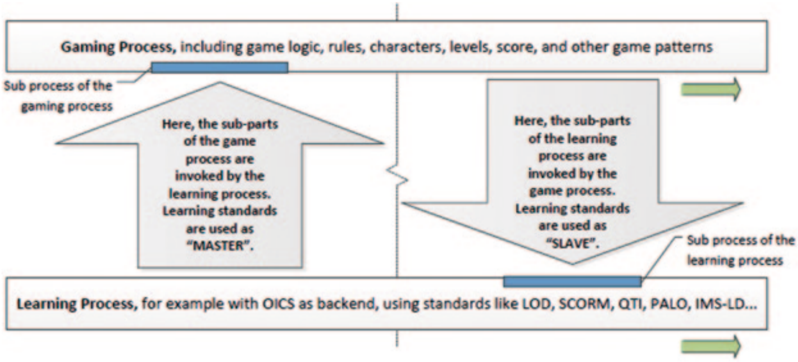


Fig. 1 The use of e-learning standards

Blackboard) and consequently it is more feasible for developers to develop the games for specific VLEs.

We have discussed some aspects related the technological issues that must be taken into account in order to integrate digital games into e-learning. However, the main challenge is not technical but is largely a methodological issue. In the next section, we will discuss how to integrate digital games for learning.

Pedagogical Challenge for the Integration of Digital Games into Learning

The way that digital games are implemented for training is strongly influenced by the evolution of technology. One of the most important features in the advance of digital games is the interaction between the game and the player. Although some games still use the keyboard, many others require a device to be pointed at a screen (Nintendo's Wii), direct interaction with full-body motion (Kinect) or using finger movements on the screen. A number of technologies are on the horizon to provide an even more immersive environment than is possible today (such as 3D and augmented reality). Haptic computing, which adds the sense of touch to the simulated or virtual environment, is already being used in medical training. Nintendo's Wii platform has brought awareness of haptics to the consumer market, opening the door to new learning design and gaming innovations. For this reason, the application of video games in training is very varied (e.g., social science, physics, mathematics, sport), and we cannot establish a unique methodological approach for game-based learning. A systematic meta-analysis of the uses of digital games for learning (Clark et al. 2014) reveal that games with augmented designs for learning improve learning relative to standard versions. This finding highlights the importance of design in learning outcomes. Comparing multiple game-based interventions to one another indicate that certain types of game structures may be more effective for certain types of outcomes. It is very important the design beyond simple choice of medium when discussing the affordances of digital games for learning. Although this conclusion is quite obvious, the role of design does not appear in debates over whether digital games are "better" or "worse" than traditional instruction. For this reason, it is very important to consider this finding when interpreting the media-comparison analyses. In this section, we will describe the main elements to take into account when designing the use of digital games in formal education.

Despite the benefits of digital games mentioned previously, their integration into formal education is scarce and different problems have been identified. First and most notably, there is a lack of acceptance of games as educational tools among the majority of educators (Egenfeldt-Nielsen 2006; Felicia 2009; Hwang and Wu 2012; Wastiau et al. 2009). Some teachers perceive the use of games as a leisure time activity with no pedagogic value. In addition, teachers have problems integrating games into a regular classroom. There are many products and it is difficult for them to select the appropriate game for each educational purpose. For this reason, some associations are developing networks of teachers to promote the use of digital games by providing examples and criteria for selecting games (de Freitas et al. 2012; Wagner 2012).

Another important problem to take into account is that playing in an informal situation is not the same as playing in a formal setting. For instance, a meta-analysis of the cognitive and motivational effects of serious games reveals that "between leisure computer games and serious games is that the former are chosen by the players and played whenever and for as long as they want, whereas the type of game that is used and the playing time are generally defined by the curriculum in the case of serious games. Within the instructional context, it is possible that the lack of control on these decisions has attenuated the motivation appeal of serious games" (Wouters et al. 2013, p. 260).

The main goal for a player is to have fun and not to learn. For this reason, implementing games for learning purposes requires designing activities in which the game is part of a learning scenario. Learning does not just end with the game.

These problems are not only related to primary and secondary education. The Horizon Report for Higher Education (NMC 2011, 2012) mentions the use of serious games as a promising area to support learning in universities and identifies the time-to-adoption for games and gamification as 2–3 years. However, the real adoption and institutional implementation of games in post-secondary education is still at an experimental stage—we can find some isolated experiences but there is no systematic implementation (Epper et al. 2012). De Freitas and Oliver (2006) consider that there are four aspects to take into account when planning to use digital games for learning: learner modelling and profiling, the role of pedagogic approaches for supporting learning (e.g., associative, cognitive and situated), the representation of the game itself (how high the levels of fidelity need to be, how interactive the game is and how immersive the game might be), and the context within which learning takes place (e.g., discipline and setting).

Table 1 Game elements grouped according to the four-dimensional work (van Staalduinen and de Freitas 2011)

Learner Specifics	*Pedagogy*
Challenge	Adaptation
Conflict	Assessment/Feedback
Progress	Debriefing/Evaluation
	Instructions/Help/Hints
	Safety
Representation	*Context*
Action-Domain Link	Fantasy
Control	Goals/Objectives
Interaction (Equipment)	Language/Communication
Interaction (Interpersonal)	Mystery
Interaction (Social)	Pieces or Players
Location	Player Composition
Problem–Learner Link	Rules
Representation	Theme
Sensory Stimuli	

The elements of the games detailed above are quite varied; however, they all fit into one of the four mentioned categories: learner, context, pedagogy and representation. For this reason, van Staalduinen and de Freitas (2011) have proposed joining up the elements (see Table 1).

Hanghøj and Brund (2010, p. 116) state: "Game-based teaching can be understood as a complex series of pedagogical choices, practices and meaning-making processes, which can be analysed through the complimentary notions of teacher roles, game modalities, and positionings". To a certain degree this teacher-centred standpoint can be seen as an alternative, or complimentary, take on the four-dimensional model. The proposal (see Fig. 2) identifies a repertoire of different roles that

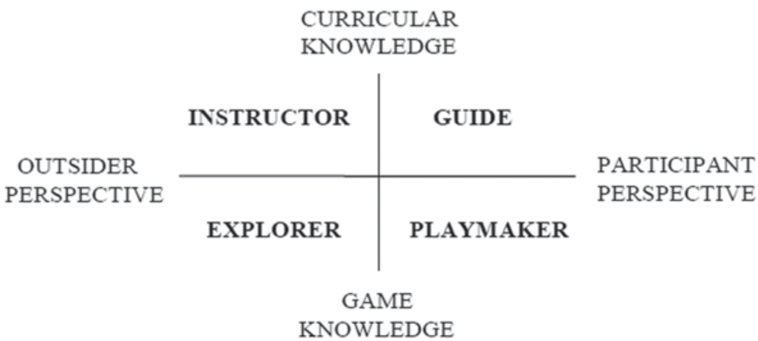


Fig. 2 The relationship between different game-based teaching roles (Hanghøj and Brund 2010)

teachers assume throughout the process, namely that of instructor, playmaker, guide and explorer. These correspond to different phases in the deployment process and can be mapped onto axes according to the type of knowledge (curricular/game) and perspective (outsider/participant) involved (Magnussen and Hanghøj 2010). This proposal provides a general framework for gaining a more concrete understanding of game-based learning dynamics from the educator's perspective.

It seems clear that to successfully integrate digital games it is essential to align the direction of learning, instruction and assessment. The design of the game must fit with the pedagogical design and the content area or the intended learning outcomes. This is most evident in the use of commercial video games as they do not have an educational purpose and, therefore, it is necessary to plan how to integrate the resource. It is easier to integrate serious games that have been created for educational purposes. Moreover, debriefing is critical for using games in education as it provides the connection between learning in the game and applying those skills to other contexts (Ash 2011; Gros 2007). Teachers can facilitate the transfer of skills by leading pre- and post-game discussions, which connect the game with other things students are learning in class.

The ultimate aim of integrating games into learning can be very varied. We propose six important directions based on the predominant reasons for integrating games: to teach twenty-first century skills, to improve motivation, to teach content, to improve learning experiences, for authentic assessment, and for design and creativity.

Games to Teach Twenty-First Century Skills

There is a growing awareness that teaching twenty-first century skills "frequently requires exposing learners to well-designed complex tasks, affording them the ability to interact with other learners and trained professionals, and providing them with appropriate diagnostic feedback that is seamlessly integrated into the learning experience" (Rupp et al. 2010, p. 4). Consequently, the use of digital games is closely related to skills like collaboration, innovation, production and design. For this reason, digital games are frequently cited as important mechanisms for teaching twenty-first century skills because they can accommodate a wide variety of learning styles within a complex decision-making context (Squire 2006).

Games to Improve Motivation

A year-long pan-European study that included over 500 teachers found that the great majority of the teachers surveyed confirmed "motivation is significantly greater when computer games are integrated into the educational process" (Joyce et al. 2009, p. 11). Most games provide clear goals, tasks and challenges, and reinforce feedback, which are important elements for improving motivation. For this reason, games are often used as a starting point for improving motivation.

www.allitebooks.com

Games to Teach Content

Commercial games or serious games can be used to teach some specific content in the curriculum. In many cases, the main challenge is the integration rather than the use of the game for learning, and to focus on solving complex problems. Most video games provide complex learning environments in which players have to be able to control many different variables, take decisions, establish strategies and constantly compare the effects of their actions in the system.

Games to Improve Learning Experiences

Kiili (2005) has developed an experiential gaming model to link gameplay with experiential learning in order to facilitate flow experience. Experiential learning describes the acquisition of knowledge in a learning cycle with four successive stages (Kolb 1984): concrete experience, reflective observation, abstract conceptualisation, and feedback or active experimentation. The core of Kolb's four-stage model is a simple description of the learning cycle which shows how experience is translated by reflection into concepts, which in turn are used as a guide to feedback or active experimentation and planning new experiences or creating alternative methods of action. In this way it helps learners to understand the process of acquiring concepts, skills and attitudes from their own point of view.

The design cycle (Fig. 3) describes the main phases of game design and works as a guideline in the design process. The design process is presented abstractly because it may vary among the different game genres. The model emphasises the importance of considering several flow antecedents in educational game design: challenges matched to the skill level of a player, clear goals, unambiguous feedback, a sense of control, playability, gamefulness, focused attention and a frame story (Kiili 2006).

Using this approach allows us to highlight a very important aspect: the gaming experience is not the same in a formal context as it is outside the school setting. Including games in a learning context aims to leverage the advantages of digital game design to enhance learning. It is important to stress that the pedagogical exploitation of video games involves bringing the game into the classroom under the guidance of teachers, who must work to make the experience of playing a reflective experience.

Games for Assessment

It is important to note that video games are inherently assessments. Assessment occurs naturally in a game due to the immediate feedback. Players make progress or they do not; they advance to the next level or try again. According to Ash (2012), the challenge lies in assessing the appropriate knowledge, skills or abilities.

The opportunity for games to be used as assessments is greatly enhanced because of their capacity to collect data about students. Shute (2013) refers to this embedded gathering of information about players as "stealth assessment", an evidence-based

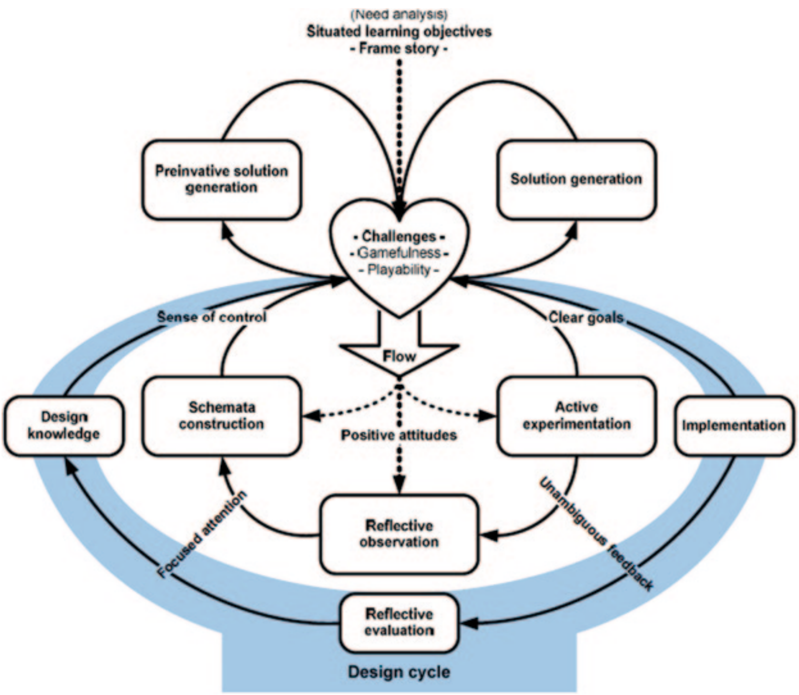


Fig. 3 Experiential gaming model (Kiili 2005, p. 18)

process by which assessment can be integrated directly into learning environments. Moreover, Shute and Kim (2011) demonstrate how assessments can be embedded within a commercial game to examine the learning of educationally relevant knowledge and skills.

Games for Design and Creativity

Another approach to using game-based learning is to ask the students themselves to design digital games to teach others. Prensky (2008) states that students are capable of game design because they are the ones that are closely related to the learning subjects and who understand most about the power of games for learning. By learning through designing games, students can increase their understanding of subject concepts, and enhance their general problem solving abilities and creativity.

This approach was very difficult to apply in the past; however, the software to produce games has improved and now provides easy tools that can be used with students. For instance, GameMaker[1] and Scratch[2] do not require professional programming abilities and support the creation of video games.

[1] http://www.yoyogames.com/studio.

[2] http://scratch.mit.edu.

Conclusion

This chapter has reviewed the current use and integration of digital games in education and has analysed the foundations of game-based learning.

The use of digital games has been shown to be successful for encouraging student participation. Possibly what is most important about digital games is the combination of motivation, engagement, adaptivity, simulation, collaboration and data collection.

Developments in gamification, serious computer games and game-based learning are becoming important for virtual learning environments (VLEs). However, the main challenge is to improve the acceptance of games as an educational tool and increase their real integration.

General perceptions of the usefulness of games to support learning are certain to improve over the next few years, as the generations learning with games in the classroom reach tertiary education and as teachers receive tools and guidance for developing their own game-based learning activities with groups of learners with different skills, levels and competencies.

We believe that research should no longer focus on whether games may be used for learning, but instead should prioritise how games can be best used for learning.

References

Arnseth, H. C. (2006). Learning to play or playing to learn: A critical account of the models of communication informing educational research on computer gameplay. *Game Studies: The International Journal of Computer Game Research, 6*(1), ISSN: 1604-7982.

Ash, K. (2011). Gaming goes academic. *Education Week, 30,* 24–28.

Ash, K. (2012). Attention, videogames and the retention economies of affective amplification. *Theory, Culture & Society, 29*(6), 3–26.

Bates, T. (2011). Understanding Web 2.0 and its implications for e-learning. *InWeb, 2,* 21–41.

Blunt, R. (2009). Do serious games work? Results from three studies. *eLearn Magazine*, *12*.

Clark, D. B., Tanner-Smith, E. E., & May, S. K. (2014). *Digital games for learning: A systematic review and meta-analysis*. SRI Publication, Technical Report.

Csikszentmihalyi, M., & Nakamura, J. (1979). The concept of flow. *Play and Learning*, 257–274.

de Freitas, S. (2006). *Learning in immersive worlds: A review of game-based learning*. London: JISC.

de Freitas, S., & Oliver, M. (2006). How can exploratory learning with games and simulations within the curriculum be most effectively evaluated? *Computers & Education, 46,* 249–264.

de Freitas, S., Kiili, K., Ney, M., Ott, M., & Popescu, M. (2012). GEL: exploring game enhanced learning. *Procedia Computer Science, 15,* 289–292.

Dempsey, J. V., Rasmussen, K., & Lucassen, B. (1996). Instructional gaming: Implications for instructional technology. *Proceedings of the annual meeting of the association for educational communications and technology*. Nashville.

Egenfeldt-Nielsen, S. (2006). Overview of research on the educational use of video games. *Digital kompetanse, 1*(3), 184–213.

Epper, R., Derryberry, A., & Jackson, S. (2012). Game-based learning: Developing and institutional strategy. *Educause*. Research Bulletin. http://www.educause.edu/ecar.

Felicia, P. (2009). Digital games in schools: A handbook for teachers. European Schoolnet's Games in Schools Project. http://games.eun.org/upload/GIS_HANDBOOK_EN.PDF.

Ferdig, R. (2007). Learning and teaching with electronic games. *Journal of Educational Multimedia and Hypermedia, 16*(3), 217–223.

Gee, J. P. (2003). *What video games have to teach us about learning and literacy*. New York: Palgrave Macmillan.

Gee, J. P. (2007). *Good video games and good learning*. New York: Peter Lang.

Gros, B. (2007). Digital games in education: The design of games-based learning environments. *Journal of Research on Technology in Education, 40,* 1–23.

Gros, B., & Garrido, J. M. (2008). The use of videogames to mediate curricular learning. DIGITEL. In M. Eisenberg, Kinshuk, M. Chang, & R. McGreal (Eds.), *Proceedings of the Second IEEE International Conference on Digital Game and Intelligent Toy Enhanced Learning, DIGITEL 2008* (pp. 170–176). Los Alamitos: IEEE Computer Society.

Hainey T., Connolly T., Stansfield M., & Boyle E. A. (2011). Evaluation of a game to teach requirements collection and analysis in software engineering at tertiary education level. *Computers & Education, 56,* 21–35.

Hanghøj, T., & Brund, C. E. (2010, October 21–22). Teacher roles and positionings in relation to educational games. *Proceedings of ECGBL 2010, 4th European Conference on Games Based Learning*, Copenhagen.

Haynes, L. C. (2000). Gender differences in the use of a computer-based mathematics game: Strategies, motivation, and beliefs about mathematics and computers. *ProQuest Information & Learning, 60*(9), 3328–3624.

Hays, R. T. (2005). The effectiveness of instructional games: A literature review and discussion (No. NAWCTSD-TR-2005-004). Naval Air Warfare Center Training Systems.

Hung, W., & Van Eck, R. (2010). Aligning problem solving and gameplay: A model for future research and design. In R. Van Eck (Ed.)*, Interdisciplinary models and tools for serious games: Emerging concepts and future directions* (pp. 227–263). Hershey: IGI Global.

Hwang, G.-J., & Wu, P.-H. (2012). Advancements and trends in digital game-based learning research: A review of publications in selected journals from 2001 to 2010. *British Journal of Educational Technology, 43,* 6–10.

Jalongo, M. R. (2007). Beyond benchmarks and scores: Reasserting the role of motivation and interest in children's academic achievement. *Association for Childhood Education International, 83*(6), 395–407.

Joyce, A., Gerhard, P., & Debry, M. (2009). How are digital games used in schools: Complete results of the study. European Schoolnet.

Kafai, Y. B., & Ching, C. C. (1996). Meaningful contexts for mathematical learning: The potential of game making activities. *Proceedings of the 1996 international conference on learning sciences* (pp. 164–171).

Kapp, K. M. (2012). *The gamification of learning and instruction: Game-based methods and strategies for training and education*. San Francisco: Pfeiffer.

Ke, F. (2009). A qualitative meta-analysis of computer games as learning tools. In R. E. Ferdig (Ed.), *Handbook of research on effective electronic gaming in education* (Vol. 1, pp.1–32). Hershey: IGI Global.

Kelle, S., Klemke, R., & Specht, M. (2011a). Design patterns for learning games. *International Journal of Technology Enhanced Learning, 3*(6), 555–569.

Kelle, S., Klemke, R., Gruber, M., & Specht, M. (2011b). *Standardization of game based learning design.* In B. Murgante, O. Gervasi, A. Iglesias, D. Taniar, & B. O. Apduhan (Eds.), *Computational science and its applications–ICCSA 2011* (Part IV, pp. 518–532). Berlin: Springer.

Khan, B. (2005). *Managing e-learning strategies: Design, delivery, implementation and evaluation*. London: Information Science Publishing.

Kiili, K. (2005). Digital game-based learning: Towards an experiential gaming model. *Internet and Higher Education, 8*(1), 13–24.

Kiili, K. (2006). Evaluations of an experiential gaming model. *Human Technology, 2*(2), 187–201.

Kiili, K. (2007). Foundation for problem-based gaming. *British Journal of Educational Technology, 38*(3), 394–404.
King, A. (1993). From sage on the stage to guide on the side. *College Teaching, 41*(1), 30–35.
Kirriemuir, J., & McFarlane, A. (2003). Literature review in games and learning. Futurelab Series, Futurelab.
Klopfer, E. (2008). *Augmented learning research and design for mobile educational games*. Cambridge: MIT Press.
Kolb, D. A. (1984). *Experiential learning*. Englewood Cliffs: Prentice Hall.
Livingstone, D., & Hollins, P. (2010). Virtual worlds, standards and interoperability. *International Journal of IT Standards and Standardization Research (IJITSR), 8*(2), 45–59.
Magnussen, R., & Hanghøj, T. (2010). Rethinking design-based research: Redefining 'Design' in relation to educational games. In Z. W. Abas, I. Jung, & J. Lucas (Eds.), *Proceedings of Global Learn Asia Pacific 2010: Global Conference on Learning and Technology* (1st ed., pp. 1592–1601). Chesapeake: AACE.
Magnussen, R., & Misfeldt, M. (2004). Player transformation of educational multiplayer games. *Proceedings of other players*. Copenhagen. http://www.itu.dk/op/proceedings.
Malone, T. W. (1981). What makes computer games fun? *Byte, 6,* 258–277.
Mayer, I. (2012). Towards a comprehensive methodology for the research and evaluation of serious games. *Procedia Computer Science, 15,* 233–247.
McClarty, K. L., Orr, A., Frey, P. M., Dolan, R. P., Vassileva, V., & McVay, A. (2012). A literature review of gaming in education. Pearson's Research Reports.
Michael, D., & Chen, S. (2006). *Serious games: Games that educate, train and inform*. Boston: Thomson Course Technology.
Moreno-Ger, P., Burgos, D., & Torrente, J. (2009). Digital games in eLearning environments: Current uses and emerging trends. *Simulation & Gaming, 40*(5), 669–687.
New Media Consortium [NMC]. (2011). The horizon report: Higher education edition. http://www.nmc.org/horizon-project.
New Media Consortium [NMC]. (2012). The horizon report: Higher education edition. http://www.nmc.org/horizon-project.
O'Neil, H. F., Wainess, R., & Baker, E. L. (2005). Classification of learning outcomes: Evidence from the computer games literature. *The Curriculum Journal, 16*(4), 455–474.
Prensky, M. (2001). *Digital game-based learning*. New York: McGraw-Hill Education.
Prensky, M. (2008). Students as designers and creators of educational computer games: Who else? *British Journal of Educational Technology, 39*(6), 1004–1019.
Prensky, M. (2010). *Teaching digital natives: Partnering for real learning*. Thousand Oaks: Corwin.
Revuelta, F., & Bernabé, A. (2012). El videojuego en red social: un nuevo modelo de comunicación. *Didáctica de la Lengua y la Literatura, 6,* 157–176.
Rollings, A., & Adams, E. (2006). *New challenges for character-based game-design*. Indianapolis: New Readers.
Rosenbaum, E., Klopfer, E., & Perry, J. (2006). On location learning: Authentic applied science with networked augmented realities. *Journal of Science Education and Technology, 16*(1), 31–45.
Rupp, A. A., Gushta, M., Mislevy, R. J., & Shaffer, D. W. (2010). Evidence-centered design of epistemic games: Measurement principles for complex learning environments. *Journal of Technology, Learning, and Assessment*, *8*(4), 1–47.
Sandford, R., Ulicsak, M., Facer, K., & Rudd, T. (2006). *Teaching with games: Using commercial off-the-shelf computer games in formal education.* Bristol: Futurelab.
Sandford, R., Ulicsak, M., Facer, K., & Rudd, T. (2007). Teaching with games. *Learning, Media & Technology, 32*(1), 101–105.
Shaffer, D. W. (2008). *How computer games help children learn*. New York: Palgrave/Macmillan.
Shaffer, D. W., & Clinton, K. (2006). Toolforthoughts: Reexamining thinking in the digital age. *Mind, Culture, and Activity, 13*(4), 283–300.

Shaffer, D. W., & Gee, A. (2006). Before every child is left behind: How epistemic games can solve the coming crisis in education (Working Paper No. 2005–7). University of Wisconsin-Madison.

Shaffer, D. W., Squire, K. D., Halverson, R., & Gee, J. P. (2005). Videogames and the future of learning. *Phi Delta Kappan, 87*(2), 104–111.

Shute, V. J. (2013). *Stealth assessment: Measuring and supporting learning in video games*. Cambridge: MIT Press.

Shute, V. J., & Kim, Y. J. (2011). Does playing the World of Goo facilitate learning? In D. Y. Dai (Ed.), *Design research on learning and thinking in educational settings: Enhancing intellectual growth and functioning* (pp. 359–387). New York: Routledge.

Shute, V. J., Ventura, M., Bauer, M., & Zapata-Rivera, D. (2009). Melding the power of serious games and embedded assessment to monitor and foster learning: Flow and grow. In U. Ritterfeld, M. Cody, & P. Vorderer (Eds.), *Serious games: Mechanisms and effects* (pp. 295–321). Mahwah: Routledge, Taylor and Francis.

Squire, K. (2002). Cultural framing of computer/video games. *Game Studies: The International Journal of Computer Game Research, 2*(1).

Squire, K. D. (2006). From content to context: Video games and designed experiences. *Educational Researcher, 35*(8), 19–29.

Squire, K. (2008). Open-ended video games: A model for developing learning for the interactive Age. In K. Salen (Ed.), *The ecology of games: Connecting youth, games and learning* (pp. 167–198). Cambridge: MIT Press.

Squire, K. D., & Klopfer, E. (2007). Augmented reality simulations on handheld computers. *Journal of Learning Sciences, 16*(3), 371–413.

Ulicsak, M., & Williamson, B. (2010). Computers game and learning. A Futurelab Handbook. http://www.futurelab.org.uk/sites/default/files/Computer_games_and_learning.pdf.

Van Eck, R. (2006). Digital game-based learning: It's not just the digital natives who are restless. *Educause Review, 41*(2), 16–30.

Van Staalduinen, J. P., & de Freitas, S. (2011). A game-based learning framework: Linking game design and learning. In. M. S. Khine (Ed.), *Learning to play: Exploring the future of education with video games* (pp. 29–54). New York: Peter Lang.

Vogel, J. J., Vogel, D. S., Cannon-Bowers, J., Bowers, G. A., Muse, K., & Wright, M. (2006). Computer gaming and interactive simulations for learning: A meta-analysis. *Journal of Educational Computing Research, 34*(3), 229–243.

Wagner, R. (2012). Learning with digital games: A practical guide to engaging students in higher education—By Nicola Whitton. *Teaching Theology & Religion, 15*(1), 91–92.

Wastiau, P., Kearney, C., & Van den Berghe, W. (2009). How are digital games used in schools? European Schoolnet. http://games.eun.org/upload/gis-synthesis_report_en.pdf.

Wouters, P., van Nimwegen, C., van Oostendorp, H., & van der Spek, E. D. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology, 105*(2), 249–265.

Zichermann, G., & Cunningham, C. (2011). Gamification by design: Implementing game mechanics in web and mobile apps. O'Reilly Media.

Begoña Gros is Full Professor in the Faculty of Education at the University of Barcelona in Spain. She is currently the coordinator of the research group, *The Design of Environment and Resources for Learning.* Her specialisation focuses on studying the integration of digital media in education and learning, and the use of video games. Begoña has published a number of journal articles and book chapters on digital media in education and learning, including *The Design of Games-Based Learning Environments* (2007), *Game-Based Learning: A Strategy to Integrate Digital Games in Schools*, *Beyond the Net Generation Debate: A Comparison of Digital Learners in Face-to-Face and Virtual Universities* (2012), and *Supporting Learning Self-Regulation through a PLE* (2013).

The Construction of Electronic Games as an Environment for Mathematics Education

Rodrigo Dalla Vecchia, Marcus V. Maltempi and Marcelo C. Borba

Abstract The main aim of this chapter is to reflect on the teaching and learning of mathematics as processes carried out through the construction of electronic games. Here, game construction is associated with the perspective of Mathematical Modeling, emphasizing the mathematical aspects specific to the programming language used by the software Scratch. In particular, we present the implicit and the explicit mathematics embedded in the construction of two games developed by university students. We believe that the quest for associations between mathematics and computational languages may help enhance the teaching and learning of mathematics as a whole. More specifically, we understand that Mathematical Modeling that takes place in the process of electronic games construction may contribute to the mathematisation process, when it considers the students' choices and interests, and takes into account the concerns with learning as it occurs throughout the construction process.

Keywords Mathematical modeling · Scratch · Computer programming

Introduction

The technological advances in recent decades have caused changes across all dimensions of human coexistence in the way people interact with one another, work, shop and present themselves to society. Such changes affect formal education, helping researchers and educators to understand digital technologies and use them

R. Dalla Vecchia (✉)
Graduate Program in Science and Mathematics Teaching,
Lutheran University of Brazil, Canoas, Brazil
e-mail: rodrigovecchia@gmail.com

M. V. Maltempi
Graduate Program in Mathematics Education, GPIMEM,
UNESP—State University of São Paulo, Rio Claro, Brazil
e-mail: maltempi@rc.unesp.br

M. C. Borba
e-mail: mborba@rc.unesp.br

© Springer Science+Business Media Dordrecht 2015
T. Lowrie, R. Jorgensen (Zevenbergen) (eds.), *Digital Games and Mathematics Learning,*
Mathematics Education in the Digital Era 4, DOI 10.1007/978-94-017-9517-3_4

in the educational process. In this sense, aiming at the construction of mathematical knowledge, we have been conducting research both on Mathematical Modeling (MM) in the context of electronic games construction (Dalla Vecchia and Maltempi 2012, 2013) and on the influence of students' choices in the development of MM activities and their relationship with Information and Communication Technologies (ICT) (Borba et al. 2008; Borba and Villarreal 2005; D'Ambrosio and Borba 2010).

However, authors like Jablonka and Gellert (2007) support the notion that the use of technologies may promote what they have called dematematisation. This term describes the trivialization and devaluing of the development of mathematics that occur when, for instance, a software is used to carry out a calculation or mathematical procedure. In this context, the authors support the notion that "For the user of technology it becomes more important to, first of all, simply trust the black box and, then, to know when and how to use it" (Jablonka and Gellert 2007, p. 8). According to Buchberger (1990), technology is used as a white box when students are aware of the mathematics they are asking the technology to carry out; in all other cases, technology is used as a black box. This confidence in the black box brings about the "myth of technological infallibility" (Jablonka and Gellert 2007, p. 8).

We understand that this belief in technological infallibility is in accordance with the Ideology of Certainty introduced by Borba and Skovsmose (1997). The authors fought the idea that mathematics is the ideal pathway (or the only one) to solve a problem, when compared with another science. They claim the existence of an ideological association between mathematics and the notion of infallibility, certainty and accuracy in the dealings with everyday problems in such a way that the discipline stands high above other standpoints. However, just like mathematics, sociology, philosophy and other disciplines may contribute to the comprehension of a given problem. We believe that, similarly to the information presented in mathematical terms, the information generated through digital technology may also be considered by many as an unquestionable truth. The fact that these technologies have a mathematical basis seems to point to some sort of shift, from the *certainty* given by mathematical argumentation to the *certainty* of the results obtained by the digital technological apparatus. Therefore, the notion of a perfect, infallible system is sustained. However:

> […] the mathematical, accurate, strict and controlled concept, as support to certain formal constructions that, no matter how similar they are to reality will never identify with it, will never capture its true rationality, of which only the surface is known. (Machado 1991, p. 78)

In other words, the relationship between reality and its description based on mathematics and built through MM is not straightforward, although this is one of the bases for the development of arguments linked to the certainty afforded by mathematics and, therefore, by technologies.

Assuming the existence of an Ideology of Certainty associated with digital technologies, we believe that understanding "what is inside the black box" may help not only to mitigate the social effect of a certainty that does not actually sustain itself, but also to advance towards an opposite direction, towards demathematisation. Additionally, our proposal may favor the understanding of the way mathematics and technologies are intertwined and how this relationship may contribute to the construction of mathematical knowledge.

In this sense, we started research work on MM as used in the context of electronic games construction in a computer. Our interest in electronic games lies in the intrinsic ludic character of these applications and in their potential in the scenario of teaching and learning processes. We resorted to the constructionist theory to justify the choice to give students the role of game designers, in accordance with our perspective of MM. More specifically, we studied electronic games construction from a constructionist standpoint, in the context of mathematical education, and understand that it may enhance educational context (Rosa and Maltempi 2010).

Constructionism (Papert 1980, 1993) is an alternative to teaching approaches that overvalue the abstract and do not aim at contextualizations that lie outside the specificity of the content addressed. For Papert (1993), the excessive value ascribed to the abstract is an obstacle to education, since this overestimation generates knowledge that is disconnected from the problems in society and from the situations associated with the student's context. In order to overcome this obstacle, Constructionism taps strongly on the use of information technologies (IT) and brings in the idea that learning is associated with the construction of something that can be demonstrated. According to this principle, the search or the construction of specific knowledge may be associated with the construction of an artifact, which in turn may generate a set of mental constructions and abstractions.

In the following paragraphs, we present the implementation of the ideas discussed above. We analyze the data collected from college students to underline the mathematics that emerges in the environment created and the consequent potential of this approach for the teaching and learning processes of mathematical contents.

Mathematical Modeling and Computer Programming

The relationship between MM and ICT is a line of investigation that is becoming increasingly consolidated in the field of mathematics education. In the Brazilian scenario, works like those of Diniz (2007), Araújo (2002), Borba et al. (2008), Dalla Vecchia and Maltempi (2009, 2010), Malheiros and Franchi (2013), and Javaroni (2007), have demonstrated the potential of this relationship. Internationally, this line of research is represented by the works of Sinclair and Jackiw (2010), Chao et al. (2010), Kazak (2010), Hills (2010), and Campbell (2010).

A brief review of the literature shows the close nature of the relationship between MM and ICT. In support of this notion, we cite the collection of texts published by Lesh et al. (2010) in the XIII International Conference on the Teaching of Mathematical Modeling and Applications (ICTMA). In that book, the authors gathered articles in sections, whose titles are written in the question form. Section 10 collects the research on MM and technology under the title *How Do New Technologies Influence Modeling in School?* It includes five papers that show, from a general

Fig. 1 An example of programming in Scratch

standpoint, the interactions between softwares and students in MM situations and leads to a reflection on how MM is understood in a reality created with technologies, which we call cybernetic world. This quest for an association between digital technologies and MM is also addressed in research conducted in Brazil, as in the works of D'Ambrosio and Borba (2010), who support the thesis that technologies not only are part of MM, but also may lead to a reorganization of thought, suggesting a differentiated construction of knowledge.

Our research indicates that the cybernetic world has singular aspects that make MM evolve smoothly, under constant transformation (Dalla Vecchia 2012; Maltempi and Dalla Vecchia 2013). In an attempt to understand these singularities and considering that the construction of electronic games paves the way for the locus of the happenings that are related to the situations of the game to be the reality of the cybernetic world, we invited the mathematics students from a university in southern Brazil to construct games in the Scratch environment, a free software developed by the Massachusetts Institute of Technology (MIT). Scratch is a visual programming language that allows users to interactively construct their own stories, animations, games, simulators, songs and art. The commands are composed of blocks that are dragged to a specific area and then connected, creating a program that can be executed. An excerpt from a program made with Scratch is presented in Fig. 1.

Therefore, in our investigation we tried not only to explore MM using technologies, but also to consider the construction of electronic games as a modeling activity. In this sense, we understand MM as "a dynamic and pedagogical process of model-building supported by mathematical ideas that refer to and aim to address problems of any dimension of reality" (Maltempi and Dalla Vecchia 2013). This understanding creates the possibility to create constructions using a programming language as model in the sphere of MM (Dalla Vecchia and Maltempi 2013). Compared to the programming using Scratch, such models can incorporate sounds and visual-aesthetic aspects as well as spoken language into their structure, which constitutes a type of model that differs from those commonly used in formal mathematical language. Thus, since it does not have a formal mathematic symbology, as usually observed in academic studies, programming in Scratch may be seen as a contribution to demathematisation.

We oppose this notion, since we defend the idea that, in a society shaped by digital technologies, we are required to understand what these technologies stand for. In this sense, we believe that the consideration of one single formal mathematical language in the academy may add to the conservation of the Ideology of Certainty also in technological terms, since the mathematics that is intrinsic to the digital

www.allitebooks.com

context may manifest itself differently from the way it is commonly perceived in the classroom. Based on these arguments, we investigated MM in the context of electronic games. The aim is to contribute to the teaching and learning processes of mathematics and to the demystification of the notion that the computer generates results that ensure certainty.

Methodology and Procedures

Aiming to investigate MM in the context of games guided by qualitative research methodology (Lincoln and Guba 1985), we offered a course entitled *Construction of Electronic Games*. Eight university-level mathematics students participated in the course, which took place in eight 4-h periods from May to July in 2009. Data collected included observations of their conversations and gestures, their interactions with each other and the software and other media utilized as part of the course. Data was collected using written notes, cameras and mainly by means of the Camtasia software, which makes it possible to capture simultaneously the image of the computer screen and images and audio of the students as they interact with them. Parts of the video and audio recordings were transcribed, categorized and analyzed according to our theoretical referential. The main software program used was Scratch.

In this chapter, we analyze data collected with two groups of students in interaction with the first author of this chapter, who administered the course. The first group, Laura and Ana, decided to create a game in which a car, controlled by the player, would navigate around obstacles that appeared on a road (see Fig. 2).

Fig. 2 Image of the game developed by Laura and Ana

Fig. 3 Image of the game developed by Eduarda and Fernanda

Another pair of students, Eduarda and Fernanda, decided to create a game in which the objective was to navigate on a map of a fictitious city by changing two variables, denoted *meters* and *degrees*. The map was initially created based on an image the students obtained from the Internet (Fig. 3).

The Mathematics Involved in the Activity

In the scope of this chapter, we shall focus on the mathematics that occurs either implicitly or explicitly in the games constructed by the students, and analyze the models developed (program parts).

To achieve their objective, the first group of students made changes in the model associated with the movement of the car throughout the construction process. In the first model, presented in Fig. 4a, there are in fact no limits to the movement of the car. In Fig. 4b, however, the model includes conditioners that allow movement only within stipulated bounds.

In mathematical structural terms, the organizations of both the initial and the final model blend propositional logic and algebraic-geometrical aspects. In fact, the model presented in Fig. 4a (called M_1) may be seen as dependent on two distinct propositions that condition the movements of the object car (called A_1 and

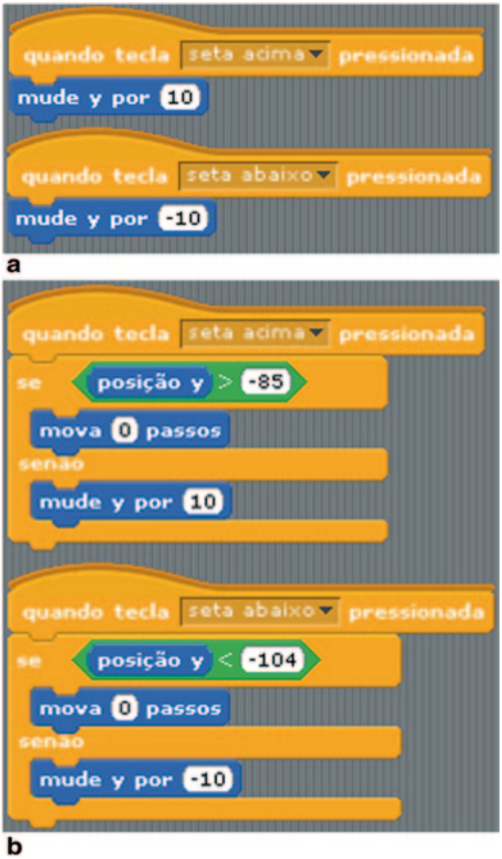


Fig. 4 **a** Initial model **b** Final model

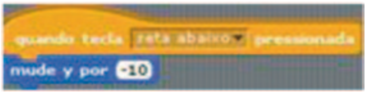
A_2). Each of these propositions (P) is related to the other two, by means of a conditional connective (operator)[1] (represented by the symbol $\rightarrow$). The first of these propositions refers to the use of the arrow key (called p), while the second refers to the change in position on the y axis (called q).

[1] The Conditional, also called Implication, is an operation between propositions that is characterized by the symbol $\rightarrow$. Given any two propositions p and q, the operation $p \rightarrow q$ may be read as "if p then q". According to Rocha (2006, p. 77), the "[…] composite proposition that results from the operation of implication of a proposition into another will be false only if the antecedent proposition [p] is true and the consequent [q] is false. In all other cases, the resulting proposition will be true".

Thus, it is possible to describe the initial model as:
M_1 (A_1, A_2), where A_1 and A_2 are composite propositions so that

$A_1 = P(p_1,q_1) = p_1 \rightarrow q_1$

$A_2 = P(p_2,q_2) = p_2 \rightarrow q_2$



Where

p_1 is "up arrow key pressed"

p_2 is "down arrow key pressed"

q_1 is "replace y by 10"

q_2 is "replace y by −10"

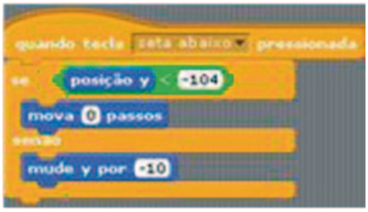
The final model (Fig. 4b) has a more complex structure that involves different operations between propositions. Of these, exclusive disjunction is underlined, which may be denoted by the symbol $\underline{\vee}$. Given two propositions p and q, the operation $p\underline{\vee}q$ is read as "either p or q". In this case, the resulting composite proposition "[…] is true only if the propositions involved in the operation have opposite logical values, that is, if one is true and the other is false" (Rocha 2006, p. 74). The negation of a proposition was also used in this model and was denoted by the symbol ~, which, according to Machado and Cunha (2005), denies the proposition, transforming a truth in a falsity, and vice versa.

Similar to the initial model, the final model (M_2) also depends on two actions, one that conditions the vertical movement along the positive direction in the y axis (upwards), and one that denotes the vertical movement along the negative direction in the y axis (downwards). We called these propositions A_3 and A_4. Using this notation, we describe the final model:

M_2 (A_3,A_4), where A_3 and A_4 are composite propositions, so that

$$A_3 = P\left(p_{11}, q_{11}, q_{12}, r_{11}\right) = p_{11} \rightarrow [(q_{11} \rightarrow q_{12})\, \underline{\vee}\, (\sim q_{11} \rightarrow r_{11})]$$

$$A_4 = P\left(p_{21}, q_{21}, q_{22}, r_{21}\right) = p_{21} \to [(q_{21} \to q_{22})\, \underline{\vee}\, (\sim q_{21} \to r_{21})]$$



Where

p_{11} is "up arrow pressed"

q_{11} is " position y >−85"

q_{12} is "move 0 steps"

r_{11} is "replace y by 10"

p_{21} is "down key pressed"

q_{21} is "position y <−104"

q_{22} is "move 0 steps"

r_{21} is "replace y by − 10"

This analysis of the constructions developed by the students shows that Scratch enables the manipulation of concepts and symbols according to logical formal rules (propositional calculus), though these usually are implicit to the programmer. Therefore, the Scratch programming language, although it is similar to natural language, has a clear mathematical basis.

However, Scratch also makes it possible to treat and discuss mathematics explicitly. Such is the case of the model constructed by the pair Eduarda and Fernanda, shown in Fig. 5.

Fig. 5 Model that refers to the movement of the object along the map

The main difference compared with the first model lies in the fact that the second uses variables in its structure that the participants called *Graus* (degrees) and *Metros* (meters) , . In this case, the movement of the object is made possible when the player changes these variables. This movement is carried out in the Scratch interface, based on the movement of a scroll bar  that allows choosing a value for *Graus*, indicating rotation of the object, and one for *Metros*, which refers to the number of steps that have to be taken towards the direction chosen.

In mathematical terms, what we see is that the movement of this point towards the next is made possible by the same ideas used in *polar coordinates*, that is, considering the starting point of each change as an origin, the final point of the movement may be represented by the pair (r, θ), where r is the radius (the variable meters) and θ is the angle (the variable degrees). This way of moving the object is linked to a larger structure that involves, apart from movement, the interaction with other objects included in the game.

The manipulation and the understanding of the variables is an essential step in the development of algebraic thought and mathematical generalization (Mason 1996). Yet, this structure may also be interpreted in propositional logical-mathematical terms. Differently from the logical-mathematical models previously introduced, this model requires, apart from the operations already presented, logical operators "and" and "or", represented by the symbols $\wedge$ and $\vee$, respectively. According to Rocha (2006) and Machado and Cunha (2005), the use of the operation "and" between two propositions is only true when both assume true logical values and the other possible combinations are false, while for the operation "or" the false logical value will only be assumed true when both are false and the other combinations are true. If movement is called M, it may be described as:

$M\,(G, N, A)$, where G, N and A are composite propositions so that

G is associated with the object spin and may be expressed as

$$G = p \rightarrow (g \rightarrow q)$$

Where

p is the "green flag" key, when clicked 

g is the change in the variable *Graus* 

q is the spin caused by the change in the variable *Graus* 

N is associated with the movement of the object, expressed by

$$N = p \rightarrow (m \rightarrow r)$$

Where

p is the "green flag" key, when clicked 

m is the change in the variable *Metros* 

r is the movement caused by the change in the variable *Metros* 

A is associated with the position of the object after variables are changed, which makes it return to its initial position, if it went beyond the map outline (since its color, which is red, overlaps the grey color, attributed to the map outline).

$$A = [p \wedge (q \vee r)] \rightarrow (t \rightarrow u)$$

Where

p is the "green flag" key, when clicked 

q is the spin caused by the change in the variable *Graus* 

r is the movement caused by the change in the variable *Metros* 

t is the sensor "color touches color" 

u is the command "go to" 

Therefore, it is possible to observe that a series of logical-mathematical concepts is associated with the model constructed. These concepts show that movement M depends on three composite propositions, composed by G, N and A, which in turn are organized by operations between simple propositions. Apart from this, in the specific case of the construction developed by the students, explicit mathematical aspects were presented, such as the use of angle and movement, which may be associated with the context covered by the study of polar coordinates.

Conclusion

In this chapter, we present aspects linked to the mathematics that exists in the process of electronic games construction. The analysis of the process revealed that the construction of these games using the Scratch software, besides having an implicit mathematics based mainly on the logic of propositional calculus, shows that aspects associated with the mathematics used in the school and university contexts may emerge, as was the case with the second group of students. We believe that the fact that these aspects may contribute not only to improve the teaching and learning of mathematics, but also to propel a mathematisation process mediated by technologies is a particularly interesting aspect. This underlines the construction of knowledge in a distinct way, which takes into account the choices made by the students, their interests and the learning process that occurs throughout construction, in agreement with the ideas proposed by Papert (1980, 1993). Therefore, apart from stimulating the comprehension of "what is inside the black box", the process of electronic games construction may help demystify the *certainty* that many times springs from the use of technologies, since it affords to address the programming process responsible for the whole structure of softwares. Also, it becomes clear that this process is nothing but a construction accountable to criticisms and mistakes and that, implicitly, may carry a series of implicit ideologies.

Specifically concerning the focus of this chapter, we understand that our main challenge in future research is the quest for ways to explore the potential of implicit mathematics in a learning process that retains its ludic character, using the construction of electronic games. We understand that the balance between these aspects should be considered in order to prevent the creation process from congealing itself, which would go against some of our premises that involve the participation of the student in the choice of what they desire to develop.

Computer programming affords great potential for creating activities that can contribute to the construction of specific mathematical concepts. In particular, we intend to focus on activities that can highlight the implicit mathematics in the program Scratch, which involves propositional (predicate) logic. In such environments, inference rules can be used to organize and structure program to contextualize propositional calculus.

In addition to the potential concerning the association with the process of construction of mathematical knowledge, we understand that the research presented enlarges the comprehension of MM itself. This part of the research presented affords to rethink the comprehension of what is understood by the model, in the context of MM. The Scratch language allows constructing structures that use aspects of the mother language, of the aesthetic/visual context and sound aspects by means of commands that may be *locked in*. This shows a type of model that is distinct from those models commonly used in a formal mathematical language and that can be seen as such only in the cybernetic world context where it finds support and the means to update itself. Due to these particularities, we understand that it is coherent to treat this model as a mathematical/technological model (Dalla Vecchia and Maltempi 2013).

When we associate the construction of electronic games with MM, it is possible to discuss and rethink the aspects linked to the mathematical model. Also, the reference to reality—an aspect that seems to run through the different ways MM is understood (Dalla Vecchia and Maltempi 2012)—is likewise an object of our attention, since the situations constructed by students are developed in ways that allow them to update themselves in the space opened by technologies, popularly known as virtual reality. Numerous questions are the object of our concerns and prompt us to search for answers that connect the theory, philosophy and application:

- Can virtual reality be considered a reality?
- Can virtual reality become a field of reference for MM?
- What are the qualitative changes that take place when MM is realized in the cybernetic world?
- What are the contributions of the association between MM and the construction of electronic games both to the teaching and learning process, and to the comprehension of MM itself?
- Is there an ideal language to use in MM?
- How does the association between reality and mathematics occur?
- What is the relationship between problem solving processes and MM?
- How does the MM process take place?

These questions represent the pathway we follow and intend to investigate more thoroughly in our future research efforts.

References

Araújo, J. L. (2002). *Cálculo, tecnologias e modelagem matemática: As discussões dos alunos*. UNESP. Tese (Doutorado em Educação Matemática), Instituto de Geociências e Ciências Exatas, Universidade Estadual Paulista: Rio Claro (Brazil).

Borba, M. C., Malheiros, A. P. S., & Zulatto, R. B. (2008). *Educação a distância online*. Brazil: Autêntica.

Borba, M. C., & Skovsmose, O. (1997). The ideology of certainty in mathematics education. *For the Learning for Mathematics, 17*(3), 17–23.

Borba, M. C., & Villarreal, M. E. (2005). *Humans-with-media and the reorganization of mathematical thinking* : *Information and communication technologies, modeling, experimentation and visualization*. New York: Springer.

Buchberger, B. (1990). Should students learn integration rules? *SIGSAM Bulletin*, *24*(1), 10–17.

Campbell, S. R. (2010). Mathematical modeling and virtual environments. In R. Lesh, P. Galbraith, C. R. Haines, & A. Hurford. (Eds.), *Modeling students' mathematical modeling competencies* (pp. 583–596). New York: Springer.

Chao, T., Empson, S. B., Shechtman, N. (2010). A principal components model of simcalc mathworlds. In R. Lesh, P. Galbraith, C. R. Haines, & A. Hurford. (Eds.), *Modeling students' mathematical modeling competencies* (pp. 555–560). New York: Springer.

Dalla Vecchia, R. (2012). *Modelagem Matemática e a Realidade do Mundo Cibernético*. UNESP. Tese (Doutorado em Educação Matemática), Instituto de Geociências e Ciências Exatas, Universidade Estadual Paulista: Rio Claro (Brazil).

Dalla Vecchia, R., & Maltempi, M. V. (2009). Ensaio sobre a Modelagem Matemática e o virtual. In *XIII Encontro Brasileiro de Estudantes de Pós-Graduação em Educação Matemática* (Proceedings of the EBRAPEM XIII, pp. 1–15). Brazil: Goiânia.

Dalla Vecchia, R., & Maltempi, M. V. (2010). Tecnologias digitais e percepção da realidade: Contribuições para a Modelagem Matemática. In *X Encontro Nacional de Educação Matemática* (Proceedings of the ENEM, pp. 1–10). Brazil: Bahia.

Dalla Vecchia, R., & Maltempi, M. V. (2012). Modelagem matemática e tecnologias de informação e comunicação: A realidade do mundo cibernético como um vetor de virtualização. *BOLEMA: Boletim de Educação Matemática, 26*(43), 191–218.

Dalla Vecchia, R., & Maltempi, M. V. (2013). *The model in Mathematical Modeling in the reality of the cybernetic world*. Blumenau: ICTMA.
D'Ambrosio, U., & Borba, M. C. (2010). Dynamics of change of mathematics education in Brazil and a scenario of current research. *ZDM Mathematics Education, 42,* 271–279.
Diniz, L. N. (2007). *O papel das tecnologias de informação e comunicação nos projetos de Modelagem Matemática*. Dissertação. Rio Claro, Brazil: (Mestrado em Educação Matemática), Instituto de geografia e Ciências Exatas, Universidade Estadual Paulista.
Hills, T. (2010). Investigating mathematical search behavior using network analysis. In R. Lesh, P. Galbraith, C. R. Haines, & A. Hurford (Eds.), *Modeling students' mathematical modeling competencies* (pp. 571–582). New York: Springer.
Jablonka, E., & Gellert, U. (2007). *Mathematisation—demathematisation*. In U. Gellert & E. Jablonka (Eds.), *Mathematisation and demathematisation: Social, philosophical and educational ramifications* (pp. 1–18). Rotterdam: Sense.
Javaroni, S. L. (2007). *Abordagem geométrica: Possibilidades para o ensino e aprendizagem de Introdução às Equações Diferenciais Ordinárias*. UNESP. Tese (Doutorado em Educação Matemática), Instituto de Geociências e Ciências Exatas, Universidade Estadual Paulista: Rio Claro (Brazil).
Kazak, S. (2010). Modeling random binomial rabbit hops. In R. Lesh, P. Galbraith, C. R. Haines, & A. Hurford (Eds.), *Modeling students' mathematical modeling competencies* (pp. 561–570). New York: Springer.
Lesh, R., Galbraith, P., Haines, C. R., & Hurford, A. (Eds.). (2010). *Modeling students' mathematical modeling competencies*. New York: Springer.
Lincoln, Y., & Guba, E. (1985). *Naturalistic inquiry*. California: Sage.
Machado, N. J. (1991). *Matemática e realidade* (3rd ed.). São Paulo: Cortez e Editores Associados.
Machado, N. J., & Cunha, M. O. (2005). *Lógica e linguagem cotidiana*: *Verdade, coerência, comunicação, argumentação*. Belo Horizonte: Autêntica.
Malheiros, A. P., & Franchi, R. H. O. L. (2013). As Tecnologias da Informação e Comunicação nas produções sobre Modelagem no GPIMEM. In M. C. Borba & A. Chiari (Eds.), *Tecnologias digitais e educação matemática*. São Paulo: LF Editoria.
Maltempi, M. V., & Dalla Vecchia, R. (2013). *About mathematical modeling in the reality of the cybernetic world*. Antalya: CERME.
Mason, J. (1996). Expressing generality and roots of algebra. In N. Bednarzd, C. Kieran, & L. Lee (Eds.), *Approaches to algebra* : *Perspectives for research and teaching* (Ch. 5). Dordrecht: Kluwer.
Papert, S. M. (1980). *Mindstorms: Children, computers and powerful ideas*. New York: Basic Books.
Papert, S. M. (1993). *The children's machine* : *Rethinking schools in the age of the computer*. New York: Basic Books.
Rocha, E. (2006). *Raciocínio lógico* : *Você consegue aprender* (2nd ed.). Rio de Janeiro: Elsevier.
Rosa, M., & Maltempi, M. V. (2010). Electronic and online RPG in the mathematics education context. *International Journal for Studies in Mathematics Education, 2,* 111–137.
Sinclair, N., & Jackiw, N. (2010). Modeling practices with The Geometer's Sketchpad. In R. Lesh, P. Galbraith, C. R. Haines, & A. Hurford (Eds.), *Modeling students' mathematical modeling competencies* (pp. 541–554). New York: Springer.

Rodrigo Dalla Vecchia is Coordinator of the Mathematics Teachers Education degree and Professor in the Graduate Program in Science and Mathematics Teaching at the Lutheran University of Brazil. Currently, his research is focused on the relationship between mathematical modeling and the reality of the cyber world. He published in Portuguese and has some papers in English (in proceedings from Psychology of Mathematics Education [PME], the Congress of European Research in Mathematics Education [CERME], and the International Community of Teachers of Mathematical Modelling and Applications [ICTMA]).

Marcus V. Maltempi is a Professor of the graduate program in Mathematics Education and of the undergraduate course in Computer Science of UNESP (State University of São Paulo) in Brazil. His primary research interests lie around the use of information and communication technologies in mathematics education, including mathematical modeling, online distance education and teacher education. Marcus has directed or co-directed ten research projects, all of which have focused on the use of ICT in mathematics education. He currently directs a project that investigates mathematical modeling in the reality of the cybernetic world. He is well published in Portuguese and has some papers in English (in proceedings from Psychology of Mathematics Education [PME] and the Congress of European Research in Mathematics Education [CERME] as well as *ZDM: The International Journal of Mathematics Education*).

Marcelo C. Borba is a Professor of the Graduate Program in Mathematics Education and of the Mathematics Department of UNESP (State University of São Paulo) in Brazil, where he chairs the research group GPIMEM. Marcelo researches the use of digital technology in mathematics education, online distance education, modeling as a pedagogical approach and qualitative research methodology. He is a member of the editorial board for *Educational Studies in Mathematics* and an Associate Editor of *ZDM*. Marcelo has delivered invited presentations internationally in countries such as Australia, Canada, Denmark, Iceland, Mozambique, Mexico, Germany, New Zealand, Italy, Colombia, Argentina and the United States of America. He was a member of the education committee of the main research funding agency of Brazil for 4 years (2008–2011). He has also been a member of the program committee for several international conferences. Marcelo has published several books, book chapters and refereed papers in Portuguese and in English. He is the editor of a collection of books in Brazil titled *Trends in Mathematics Education* (published by Springer Science+Business Media, Inc.), which have been published over the last 12 years and include 26 books to date.

Digital Games, Mathematics and Visuospatial Reasoning

Tom Lowrie

Abstract Advances in technology have blurred the boundary between representing shapes and objects in two and three dimensions. Similarly, the capacity to translate and transform shapes and objects has moved beyond static and concrete form to representations that are increasingly dynamic and animated. This chapter describes young children's engagement with digital games as they interpret and navigate information using numeracy understandings and mathematics knowledge. In particular, the chapter highlights case studies of gamers utilising visuospatial reasoning as they solve problems in environments which require high levels of decoding. The chapter is underpinned by the notion that the embodied game space (i.e., the inside and outside space of the game environment) captures the interplay between how mathematics content is represented and the game's architecture space. This multifaceted and multimodal access to information requires quite different demands than the mathematics encountered by students in typical classroom contexts. Games used by children in the case studies include Pokémon, Prince of Persia and The Legend of Zelda: Phantom Hourglass.

Keywords Visuospatial · Representation · 2D · 3D · Spatial reasoning · Imagery · Decoding · Graphics · Dynamic imagery · Static imagery · Embodied game space · Navigation · Visualisation

Introduction

The study of visuospatial reasoning has a long history in psychology and more recently cognitive science. Visuospatial representations, like language, help to convey spatial understandings and abstract thought to others. They also help to clarify understandings and create meaning. In an age where citizens and societies have become increasingly dependent on information, such reasoning is paramount since

T. Lowrie (✉)
Faculty of Education, Science, Technology and Mathematics,
University of Canberra, Canberra, Australia
e-mail: thomas.lowrie@canberra.edu.au

© Springer Science+Business Media Dordrecht 2015

T. Lowrie, R. Jorgensen (Zevenbergen) (eds.), *Digital Games and Mathematics Learning,* Mathematics Education in the Digital Era 4, DOI 10.1007/978-94-017-9517-3_5

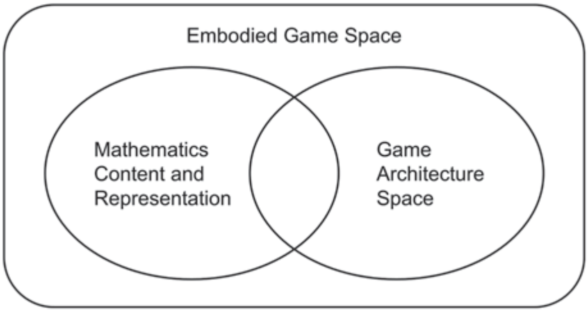
"spatial thought, spatial language, and spatial graphics reflect the importance and prevalence of visuospatial thinking in our lives" (Tversky 2005, p. 232).

Technological advances have resulted in visual and graphic displays being represented more easily, and with more detail, than was thought possible even 5 years ago. This creates different challenges for our capacity to decode images. The capacity to engage with visual and graphic displays has also changed in recent years. As Tversky (2005) maintained:

> Visual includes static properties of objects, such as shape, texture, and colour, or between objects and reference frames, such as distance and direction. It also includes dynamic properties of objects such as direction, path, and manner of movement. By this account, visuospatial transformations are those that change or use visuospatial information. Many of these properties of static and dynamic objects and of spatial relations between objects are available from modalities other than vision. (p. 211)

From a mathematics education perspective, most research associated with visuospatial reasoning relates to the manner in which an individual uses such processing in problem solving situations (Arcavi 2003; Lean and Clements 1981), the importance and/or limitations of such processing (Hegarty and Kozhevnikov 1999; Ramirez et al. 2012), or the extent to which one has a preference for processing information in a particular way (Stieff et al. 2012; van Garderen 2006). Although some studies have found that the actual task, or the additional perceptual elements that surround the task can also establish rich visual and spatial features, the most concentrated focus of this work is associated with multiliteracies (Kalantzis et al. 2003; Lowrie 2005) and multimodality (Kress 2009; Lakoff and Núnez 2000). Consequently, most attention has been directed toward the problem solvers' capacity to decode information or utilise encoding skills to represent the problem space. Less attention has been afforded to the influence of task structure or architecture and the relevant spatial features that are not directly related to the task. With respect to digital games, most mathematics-based studies have focused on the interaction between the gameplayer and game rather than the related spatial demands that uniquely pertain to the gaming experience. For example, the gaming environment is most influential in establishing a visuospatial construct for the player(s) and this in turn establishes embodied behaviour and practices. This collective spatial orientation is an underlying theme of the chapter since it is argued that spatial development is differently influenced and positioned in game environments than is the case in more traditional mathematics classrooms or professional contexts. Over a 10-year period analysing students spatial engagement with mathematics-related tasks in games contexts, it has been evident that the visuospatial reasoning challenges have changed—as the game architectures have become more dynamic and as students' embodied practices adapt to different devices and mobilities. Thus, even though the mathematics content, and perhaps even the representation of mathematics ideas, could be viewed as relatively constant (and consistent), the navigation to and from these tasks have changed. Furthermore, the interaction with the games (as a tool) has more scope and encompasses a different spatial world. Figure 1 illustrates the collective spatial arrangement of the gameplay. Each of the three elements contain various visuospatial demands that vary in terms of the mathematics content and processing, game architecture and the embodied game space.

Fig. 1 The spatial arrangement of gameplay



These visuospatial demands can be described within each of the three elements; however, the interplay and connectivity between these elements should also be understood since some attributes become fixed and consequently become dependent in nature. For example, dual representations of a map (in bird's eye and 45-degree perspectives) require distinct spatial demands if played on either a game that has two screens or one screen. The spatial demands also vary if the gameplayer is accessing supportive information from elsewhere (e.g., from another gameplayer or from a cheat site).

This chapter will describe how gameplayers employ visuospatial reasoning to navigate the internal (and inside) space within the game field, and the unbounded space outside these boundaries. In the first instance, this is considered in relation to how mathematics content is represented in digital games. The second section considers representation in relation to game architecture. Specifically, it describes the manner in which gameplayers make sense of multiple representations and the visual demands required to monitor and act upon static and dynamic information in game contexts. The third section considers the embodied space of gameplaying and the personalised outside space that influences personalised and cooperative gameplay. In each section, the role and nature of visuospatial reasoning is described through young students' engagement with mathematical ideas.

Mathematics Content and Representation

There is strong agreement that spatiality is essential to understanding digital games (Avraamidou et al. 2012; Gagnon 1985; Hwang et al. 2008; McGregor 2007) and visuospatial reasoning is evoked in such situations (Green and Bavelier 2006; Sims and Mayer 2002). Over the last 15 years, there has been a dramatic change in the way in which digital games are represented. As technology changes, the capacity to construct images that are detailed, dynamic and realistic has burgeoned. Interestingly, some of the most popular games for young adults (and beyond) have become more visually rich and complex while games that have high appeal for young children have tended to remain relatively simplistic, especially when compared to some of the 3D-like games currently available. For younger children the latest version of

Pokémon, for example, is not substantially different visually than an earlier version of the game was 15 years ago. In this sense, the games younger children play are much more 2D-like, while those for older consumers are moving toward extraordinarily realistic 3D images. In particular, this chapter focuses on the gameplaying of primary-aged children (5–12 years old) as they make sense of the visuospatial demands of games and the extent to which this impacts on their mathematics reasoning.

When young children engage with digital games, they are required to make decisions associated with rotating objects, positioning objects, moving within space, and locating and rearranging objects in static and dynamic environments. At the same time, there is some screen movement that requires these decisions to be made with speed and with distraction (for example, time countdown and different background depictions of the environment). The visuospatial reasoning required to make these decisions involves spatial imagery and/or object imagery. Spatial imagery involves the "ability to process information about spatial relations and manipulate objects in space", whereas object imagery is associated with the "ability to process information about visual appearances of objects and their pictorial properties (e.g., shape, color and texture)" (Blazhenkova and Kozhevnikov 2010, p. 276). Unlike most situations in the mathematics classroom, gameplaying requires these visuospatial features to be processed simultaneously. As a consequence, gameplaying affords different demands than that typically presented across mathematics curricula. Apart from this multidimensional functioning, gameplaying situations tend to require the gameplayer to solve tasks more rapidly and with more sophistication than is typically afforded problem solving experiences in the classroom.

In a more traditional grade 3 classroom, one might expect a student to represent daily maximum and minimum temperatures on a line chart (either drawing the graph by hand or using appropriate computer software). Although the data are hopefully realistic depictions of temperature variation and provide initial understandings of the relationship between the *x* and *y* axes on a 2D graph, the task is generally self contained and is closed in nature. By contrast, consider the manner in which children have to interpret line graphs within a digital game. The information in the graph is almost always related to some other set of information and commonly represented on the same screen. This information may well alter throughout the game and the information is generally traced over time—the night time temperatures may well be aligned to gameplaying in a night scene or indicating that the player needs to find warm clothing in order to move to the next level. This type of processing requires an ability to interpret the graph but also a capacity to interpret and engage with multiple forms of information simultaneously. For younger children, these representations generally involve 2D forms but become dynamic as background features change and movement within the screen space becomes essential. It is interesting how these decisions and decoding skills become quite unproblematic in gameplaying when more self-contained tasks generate such frustration and confusion in a traditional classroom setting. It would be misguided to assume that the demands of gameplaying are less complex than that of a classroom situation. Figure 2 presents a comparison of a typical classroom graph and the types of graphs children are exposed to in digital games. These representations highlight

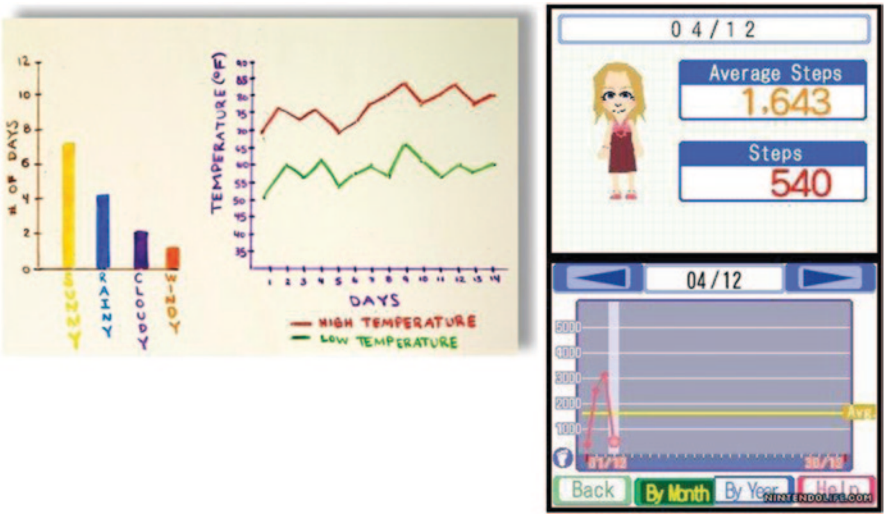


Fig. 2 Comparison of the classroom and digital game graph (Source: http://www.crayola.com/lesson-plans/weather-graphs-lesson-plan/)

the difference between the static nature of the classroom activity and the dynamic nature of the digital game graph, where the children can see the graph changing and updating as more data are inputted.

Digital games afford opportunities for a new (and potentially changing) development of visuospatial reasoning skills—where the user is actively part of the decision-making process, decoding and encoding information in an interactive manner. Rather than debate the merits of gaming for educational purposes, it may be more pertinent to consider the changing nature of visual and graphic representations. It is widely acknowledged that today's citizens require a very different repertoire of reasoning abilities that were conceived when such measures of spatial ability and visual reasoning were formulated. Given the strong relationships between static spatial abilities (especially spatial imagery aligned to mental rotations) and success in mathematics and science (Wai et al. 2009), and indeed high-stakes testing (Lowrie and Diezmann 2009), it will be interesting to see if more dynamic visuospatial reasoning developments provide similar results. Digital games, and particularly action games, have been shown to improve simultaneously students' ability to distribute attention spatially (aligned to object imagery) and mental rotations capacity (Feng et al. 2007). To what extent this transfers to current mathematics education curricula and agendas remains unclear.

Navigation and Wayfinding in Digital Contexts

The Pokémon series (Nintendo 1998) provides a rich example of how young children utilise visuospatial reasoning to solve problems. The primary goal of these

Fig. 3 A visual representation of the map illustrated in the PokéNav

games is to locate new Pokémon from unknown worlds, and then train these Pokémon to 'battle' against other Pokémon you encounter on your journeys. In order to play the game more efficiently, players access and utilise various artefacts by analysing maps in different representations and scaled forms—including graphical information from magazines. These maps included full maps that represent the entire Poké-world (see Fig. 3) and more detailed zoom maps that allow the player to navigate through towns (see Fig. 4), cities and various natural environments (including caves, mud slides and waterfalls) between these cities and towns. In addition, less detailed positional maps (see Fig. 5) are regularly analysed in order to determine one's position in relation to significant landmarks.

Essentially, the maps are utilised to locate information that is necessary to find (or catch) Pokémon. Children as young as five demonstrated the capacity to reason visually and locate information in a relatively sophisticated manner in order to solve both routine and open-ended problems within the game context. As one child commented:

> The Mountain Falls [is] the closest city you can go to. Once you go from Mauville City, that's where I am [showing the location on the screen], you go up there to there [pointing to another location on the map], then you go across here and follow that thing [a pathway], you end up in Mountain Falls. That's where the Magna Team are. You need to battle the leader two times…. And this is Everyday City right over here [pointing]. That's the whole thing. I need to go over there, that's the Pokémon Center right over there (Morgan is referring to the PokéNav that shows the whole Houen area map and the individual cities that are colour coded to represent different buildings).

The PokéNav (see Fig. 3) provided access to important information about the location of cities and pathways (routes) that are recommended for travel from one city to another. The 5- and 6-year-old children we studied routinely accessed additional

Fig. 4 A town (*Slateport City*) displayed within the Game Boy

Fig. 5 A positional map within the Game Boy

information about specific new lands and regions from the Pokémon book (some of which were in the school library). The magazines provided graphical representations of cities—including maps with different scale, orientation and perspective. Although the magazine maps were more detailed (and in a larger scale) than the corresponding graphical representations in the Nintendo DS, the children commonly cross referenced information while playing the game. The magazines became an important reference point for travel between cities because these maps provided more information within a single frame—not only was the scale easier to interpret, more information was represented within the given space. The Game Boy screen was relatively small (7×4 cm) and, as a consequence, the player would need to use scroll buttons (across eight compass-point directions) to view the information that could be represented in the magazine maps. Within the gameplay context the player is able to navigate through space in both full and zoom modes (represented in Figs. 4 and 5). The zoom mode displays information in a more detailed manner (possibly magnified tenfold) than the map that represents the Houen City. The children simultaneously moved between these two perspectives while regularly referring to the maps in the magazine.

The gameplayers' awareness of scale and proportion was illustrated in the manner in which they gestured and strategised as they played the game. For example, the players typically gestured outside of the screen space when they were about to move in that direction. Since they could only see part of the map in the zoom function mode, they (all) realised that one part of the map was connected to the other even though both parts of the map were not visible on the single screen. This required a relatively sophisticated degree of visuospatial reasoning since the player had to interpret maps of different scale while aligning paths for movement to a space (and position) not yet viewable on the screen—and this was all achieved dynamically while moving an object (the trainer) through space. Whether intuitively, or through experience, the gameplayer typically decided his or her location (that of the trainer) could be represented in different ways on the same screen (as in Fig. 5). These kindergarten and grade 1 children had not encountered notions of scale, proportion or perspective within the school curricula; yet they were able to conceptualise the relationship between landmarks in different spaces as a series of routes. Moreover, they were able to integrate these routes into networks of landmarks in ways that allowed them to make approximations of relative distances, and thus constitute a form of scale (Lehrer and Pritchard 2002). The children were able to effortlessly move between several graphical representations when describing their movement and position within the boundaries of the game and in the outside space of the game context.

New game consoles have provided different visuospatial challenges and opportunities, both within the boundaries of the game and other outside spaces. The Nintendo DS console, for example, has two screens that can be used to represent spatial information in different ways. Positional and navigational spaces can be represented in different perspectives (for example, in bird's eye and front-orientation perspectives). In some navigational-based games, the top screen of the DS provides a map of where you (i.e., the player) currently are, and all actual playing occurs on the bottom screen using the stylus. The position of the player is always shown on the map. Using the stylus, players are able to make notes on the map (see Fig. 6), chart routes for their boat (see Fig. 7) or draw paths for their various weapons.

Fig. 6 Screen shot of two screens showing player's notes on a map

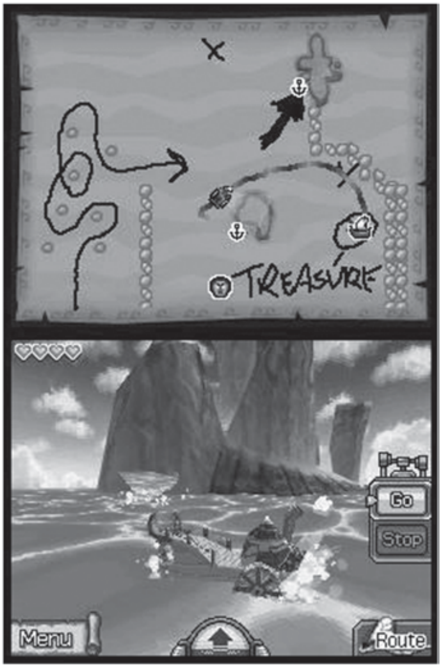


Fig. 7 Screen shot of two screens showing player's boat route and notes on the map

These positionally identical screens allow the gameplayer to process spatial concepts from different perspectives and across different representations in dynamic ways. In a typical classroom situation, opportunities for such cognitive processing are limited and are certainly not dynamic. As Lowrie and Logan (2007) argued, the development of these skills is often framed within activities that require the identification (location) of fixed and static points (e.g., coordinate grids, maps with fixed compass bearings). It is also the case that conceptual connectivity between 2D and 3D representations rarely moves beyond simple representations (e.g., identifying how many squares are in a cube). In the gaming situation, these representations are both integrated and relational.

In a game situation, the player receives immediate feedback as they decode and then interpret spatial information. Much of the information contained in graphs or maps is necessary for stage progression or for contextual understanding. In traditional classroom contexts, such embedded scenario development rarely eventuates. In the next section, game architecture and the 'space' generated from such designs are considered—partly as a description of difference and possibility.

Game Architecture and Space

If we reconsider the temperature graph scenario in the classroom, much of the processing required to solve the task is contained within the confines of the page or computer screen (for example, using Microsoft Excel). Although the teacher may present a rich or relatively authentic environment in which the data are collected, the representation always remains static and most likely fixed. Although some dynamic graphing software is now accessible to younger students, the movement of points along the x and y axes remain 'frozen in time'. In gameplaying situations, students are continually moving between inside and outside space. From a game architecture perspective, the inside space movement not only encompasses the screen, it also provides opportunity for the students to immerse themselves within the screen space (e.g., taking on the persona of the character).

The graphic design elements of games technology have dramatically increased over time, with games such as Prince of Persia, delivering quite realistic representations and scenarios as the gameplayer navigates the space. However, the architecture of the game has remained relatively constant since its inception more than 20 years ago. As Fernandez-Vara et al. (2007) have described, the spatial configuration of games is based around cardinality. They define this as the number of axes that a player is capable of moving along in the defined space—essentially within x, y and z axes. Thus, gameplayers manoeuvre along an x axis if they can only move left and right, while being able to move up and down would offer 2D space along the y axis. This is the case with Prince of Persia. Although the graphic displays have become more realistic in the most recent versions (Prince of Persia: The Sands of Time has been released) the architecture remains the same. The game world allows the player to extend in four directions, which requires utilisation of spatial orientation skills (Fernandez-Vara et al. 2007). This game is also considered to be discrete since dungeons extend in four directions, yet are not visible on the immediate screen. Movement across to another screen (either up/down or left/right) creates a maze-like configuration of space; however, any objects or other characters do not follow into subsequent screens (as is the case with Pokémon, described earlier). Games like The Legend of Zelda series follow a similar architecture. Some games provide a 2D space yet offer continuous movement. These games present images in a scroll-like manner so the gameplayer develops a sense of progression as they move across space. However, the fixed cardinality dictates that this space must be arranged either vertically or horizontally. As Fernandez-Vara et al. (2007) maintained, the gameplayer is exposed to an enhanced sense of travelling. With continuous games, the gameplayer is less likely to be required to make decisions about spaces they cannot see since the game is more like a movie with the objects and characters moving toward and away from 'you' as the fixed point. An example of this would be Grand Turismo 5. By contrast, Prince of Persia requires 'leaps of faith' onto other screens that are yet to be viewed.

Other games utilise 3D gameplay where the player can move along three axes (*x*, *y* and *z*). These games encourage different forms of navigation and exploration since "the freedom of movement is larger…[requiring] a better sense of orientation since the point of view of the character is always contained within the screen" (Fernandez-Vara et al. 2007, pp. 166–167). These games, however, offer different spatial elements that evoke other visuospatial skills (for example, movement between and across different perspectives). This is achieved when the perspective of the character can move between first person, third person and/or floating camera view.

Discrete game designs, whether within 2D or 3D representations, promote "object-based transformations [that] allow imagining an object in a different orientation", while continuous designs encourage "perspective transformations [that] allow imagining changes in one's viewpoint" (Zacks and Tversky 2005, p. 271). According to Zacks (2006):

> Many spatial reasoning problems could in principle be solved using either an object-based transformation or a perspective transformation—however, people appear to be adapted to use different specialised spatial transformations in different situations. This may because imagery systems construct simulations based on previous actual perceptual-motor experiences. (p. 2654)

The game design, whether classified as 2D/3D and/or discrete/continuous, requires different visuospatial reasoning skills. Perspective-taking ability, for example, is particularly advantageous in finding locations and landmarks along a route and interpreting relationships between small- and large-scale (navigational) space (Hegarty et al. 2002). Object-based transformations are most effective when encoding information or making sense of spatial relations of objects with respect to other objects. One reason digital games offer such potential for promoting visuospatial reasoning is due to the fact that many of the 2D and 3D games on the market today encourage the gameplayer to access and process these transformations regularly, and sometimes simultaneously.

In most game designs, the outside space contains extensive landscapes beyond the confines of the immediate screen. In fact, even the simplest of games have extensive, large-scale environments beyond that of the current gameplaying viewpoint. Not only does this make the decoding of information differently challenging, it requires increased visualisation skills in order to make decisions about information and strategies that are yet to be negotiated. The fact that visuospatial thinking requires different forms of decision making than would be the case within traditional static contexts (and even dynamic forms) is a place for further investigation. Gameplaying creates a time dimension to visuospatial reasoning that creates a fourth dimension to space—with the x, y and z axes contextualised within ‘moving events’. McGregor (2007) maintained that there was a form of situatedness that ensured that game space was always connected to real space. According to McGregor (2007), gameplayers bring their spatial and social practices to the game world through “unconscious familiarity with socially encoded environments” (p. 2).

Unlike the representation of the week’s temperature range (presented earlier in the ‘traditional’ classroom scenario), gameplaying evokes a form of embodiment that is very much task oriented and conditioned by the situatedness of the game context—resulting in the interpretation of the temperature graph becoming more experiential (that is, if the temperature plummets I need to find warm clothing, otherwise my character will die). The gameplayer must decode the graph, decide when it becomes ‘too cold’ and strategise around that situation. As McGregor (2007) intimated, “game space is situated as discrete from real space, yet remains dependent on it” (p. 2). The game space environment creates a form of embodiment that connects the player to the game context in ways that make the interpretation of a temperature graph just as ‘contextualised’ as recording the daily temperature in the classroom—yet with the added requirement to engage with and act upon the data presented. As Van Eck (2006) suggested, successful digital gameplaying involves continual predicting, theorising, reflecting and revising. The game architecture dictates that these skills and processes are situated in environments that require visuospatial reasoning.

Embodied Game Space

Multiple Representations and Visuospatial Reasoning

Another aspect of this chapter is to describe the manner in which students make sense of these multiple representations and the visual demands required to monitor and act upon static and dynamic information in game contexts. To this point, the chapter has discussed how this occurs both within the confines of the bounded screen (or screens) and subsequent screens not yet displayed. The gameplayer also brings a personalised outside space that may well be idiosyncratic to the gameplayer but often influenced by other gameplayers commonly playing the game in a different way. The section will focus on children’s willingness to share game strategy and information with one another while still playing the game individually. Thus the outside space takes two forms: the gameplaying space that cannot be seen on their immediate screen, and the shared and cooperative decision making that takes place among peers that may be directly or indirectly related to the game.

Some digital games have an elaborate set of information artefacts associated with the actual game and its pertinent console. These artefacts often include webpages (both official and fan sites), cheat sites, supplementary story books and information texts, trading cards, television shows and the like. These artefacts go well beyond what could be considered merchandise or advertising material to include specific information to value add to the game experience.

These artefacts create multiple spaces in which relevant information can be accessed, decoded and acted upon. There is a view that spatiality and visuospatial reasoning is conditioned on situation rather than positions, since game space becomes a form of reality. According to McGregor (2007), the prevalent patterns of spatial use are:

- Challenge Space: where the environment directly challenges the player.
- Contested Space: where the environment is a setting for contests between entities.
- Nodal Space: where social patterns of spatial usage are imposed on the game environment to add structure and readability to the game.
- Codified Space: where elements of game space represent other non-spatial game components.
- Creation Space: where the player constructs all or part of game space as part of gameplay.
- Backdrops: where there is no direct interaction between the game space and the player. (p. 3)

These spatial arrangements can be immersed within the game space or become subsumed in the cultural artefacts that 'belong' to the game experience (Lowrie 2011).

The Pokémon phenomenon, which is the second most lucrative digital game franchise (behind only Mario, also from Nintendo), is a good example of multimodal popular culture texts, consisting of a range of different synergistic texts such as movies, videos, books, Internet cheat sites, card games, computer games, board games and as well as the digital games played on a Nintendo DS. Lowrie and Clancy (2002) maintained that students used the artefacts in a variety of ways, independently, cooperatively and in adversarial interactions, using the schemas they have acquired as a foundation to construct narratives that are internalised within the game and externalised outside the actual gameplaying context—which they referred to as internal and external narratives.

The interactive nature of the gameplaying allows the participant to move in and out of the fantasy world. They are able to make connections between themselves in the 'real world' and their persona within the game context. In developing these personas the players establish quite sophisticated links between worlds. These links often establish journeys (or pathways) both within the confines of the game, and the outside world embodied by the game experience. The journeys create placeholders of markers that position the gameplay inside or outside the game space. These embodied contexts are certainly spatial in nature, and the shared conversations that surround these journeys establish a learning discourse quite different to that which typically takes place in classroom contexts. The capacity to pretend, predict and imagine establish rich visuospatial contexts due to the gameplaying experience.

The gameplayers make meaning and establish scenarios that become both realistic and authentic, despite the make-believe world and scenarios that surround the franchise. The authenticity of the journey is not solely created by a magnified power—it is embedded in the concrete artefacts that surround the Pokémon world. The artefacts include the television show, the playing cards and the cheat sites. With Pokémon X and Y released in 2013 (17 years after its inception), approximately 650 fictional species (characters) have been introduced to game contexts. As Sefton-Green (2004) argued, players learn to accept the rules and structures that actually break the spell of fantasy but often create explanations for events that make far more intuitive sense. It seems to be the case that players "derive these rules either from [their] understanding of social behaviour or from [their] explanation that characters in the game should behave in accordance with the genres in which they are embedded" (Sefton-Green 2004, p. 161).

In a series of investigations undertaken with 5- and 6-year-olds over a 2-year period, we (Lowrie and Clancy 2002) described the strategising, problem solving and collaboration young children undertook when playing Pokémon. In a number of observations in the children's homes, it was apparent that children engaged solely with the hand-held game despite the availability of many of the artefacts described above. The children described making decisions and justifying their movement within the game space based on a wealth of knowledge about the game and the characters associated with the game. Little reference was afforded to information in books and on webpages with the children providing compelling cases for their decision making. By contrast, their engagement at school involved sharing information with one another and reflecting upon their home experiences within game situations. They openly shared statistical and graphical information about Pokémon profiles which described characteristics and attributes of the respective characters that were valuable for gameplay. Although the hand-held games were banned from school and the playground, the associated artefacts (apart from the trading cards) were able to be taken to school. We recorded enlightening transcripts of the children analysing graphical data and comparing these data even though the scale and representation of these data were dissimilar. In fact, the level of analysis and comprehension required to interpret the graphs were well beyond the second level of Friel et al.'s (2001) description of data interpretation, that is, to read between the data. Children were identifying relationships and making inferences from the different forms of graphics associated with these games.

Representationally, the children were able to build on one another's understanding of both the mathematics concepts and gameplay strategising in a multimodal manner. This development was open-ended in nature in the sense that there were no specific rules or goal setting (Gee 2007), with groups of children (4–5 students) building on their collective strengths and then going back to the isolation of their home to practice and engage with the console. When situations became too challenging, there were always the Internet cheat sites to help along the way but this seemed to be the last resort.

Most children of this age, and in fact for years beyond these students' ages, find it difficult to interpret graphs, let alone make sense of information when represented in different scale or proportion. The movement between the small screen size to that of an A4 magazine required the students to move beyond seriation-like interpretation of bars on a graph. Once this knowledge was established other visuospatial capacities needed to be utilised. For example, interpreting that a Pichachu had specific strength and power attributes compared to that of a Rhyhorn was challenging enough, but to then encounter another 'new' Pokémon in a game situation required multiple interpretations that had to be acted upon in a timely manner. The game architecture allowed students to learn from their mistakes nevertheless; we observed that the decision making was often thoughtful and reasoned. It was also well justified and went beyond the trial-and-error nature of some gameplay—but frequently reflected collaborative conversations that had taken place with peers.

Navigation within the Pokémon regions was conducted in different ways by the children. Some created an inside space where they took the identity of a Pokémon as they moved within the screen space and beyond to other screens outside their current viewing space. This inside space included personal gesturing and a form of embodiment that allowed the gameplayer to move in and out of the game experience. Others commented that the current viewing space was just one aspect of a much larger Pokémon land as if the game console was capturing a magnified version of a much larger space. These children often reported that they did not feel part of the game but rather manoeuvred the game space through the game console (as a tool).

Tversky and Hard (2009) found that a character (or person) in a screen changed the way gameplayers thought about and described spatial relations among objects in the scene. In their study, they found that some participants took the perspective of the character instead of their own perspective, while others commonly took the viewpoint from their own space—however when a question was posed regarding an action or movement, the majority took the perspective of the former. They concluded that taking other's perspective was more natural than taking one's own perspective. The author's work with young children supports this—perspective-taking between inside and outside space occurs spontaneously and seamlessly.

Although the children playing Pokémon displayed quite specific embedded actions outside the confines of the game space, disembodied thought (e.g., Tversky 2005) took place. An imagination-based space, which included engagement with peers, established a make-believe world that encompassed rich embodied cognition as the gameplayers positioned and repositioned the spatial processing of information. Nevertheless, and despite the real presence of their own space (Tversky and Hard 2009), the children were able to view worlds from multiple perspectives—often at strategic times along the decision-making continuum.

Enacting the Spatial Arrangements: A Case of Two Gamer Profiles

The author's research suggests that there are two distinct player profiles in relation to how children manage the visuospatial challenges of a game. The first profile is associated with those gameplayers who are attentive to important features and representations on a given screen frame. Characteristically, these players tend to be deliberate, seldom make mistakes and read most texts presented on a screen including pop up text which reveals clues or contextual information. These players tend to not look beyond the screen frame in view and problem solve in a sequential and scaffolded manner. They tend to enjoy the logic and systematic (see Gee 2007) nature of gameplay and view the game as a process. They rarely miss clues and like to collect rewards and icons along the way as part of the journey. As they move through stages of the game, their decision making is often influenced by what has come before. For example, if they collect a reward along the way, they feel compelled to use it at some stage in the game. Interestingly, the detailed attention they pay to the screen often results in a loss of direction or order since they tend to be as influenced by the distractions as they are with the clues and hints they collect along the journey.

The second profile is associated with gameplayers who move through the game space rapidly, frequently engage in trial and error, pay less attention to text, view the game holistically and simultaneously engage with spatial elements of the game. Their mission in gameplay is to move through the game as quickly as possible in the most direct route. They may miss much along the way, but reach the final destination quickly.

From our experience (Lowrie and Jorgensen 2011), we have noticed that girls are more likely to belong to the first profile category, and boys the second. These characteristics tend to be sustained from the early years of school (when the children are 5 years of age) through to middle school (e.g., 15 years old).

In terms of the spatial arrangements of the gameplay presented in Fig. 8, these two game profiles highlight distinct differences in how players engage with the spatial features of the game and the visuospatial aspects of problem solving.

Navigation and wayfinding in digital contexts moves from global and directional (Profile 2) to concentrated and positional (Profile 1). The game architecture dimensions cluster around multifunctional and multimodal (Profile 2) to text rich and sequenced (Profile 1). The embodied spaces range from cooperative and competitive (Profile 2) to personalised and reflective (Profile 1). The two profiles can be represented across three continua in terms of 'gameplay style' in a similar manner (representationally at least) to Kolb's (1976) Learning Style Inventory. Kolb's (1976) Inventory describes learning style in relation to approaches taken to solve tasks. He argued that learning styles involved: (1) diverging, which described innovative and imaginative approaches to doing things; (2) assimilating, where the problem solver prefers to collate observations and thoughts and describe in an holistic manner; (3) converging, where practical applications are preferred over interpersonal ideas; and (4) accommodating, where trial and error is preferred over reflection in a discovery-like manner. Kolb's model describes these four thinking aspects along two continua (see Kolb 1976 for more details regarding the components of his model).

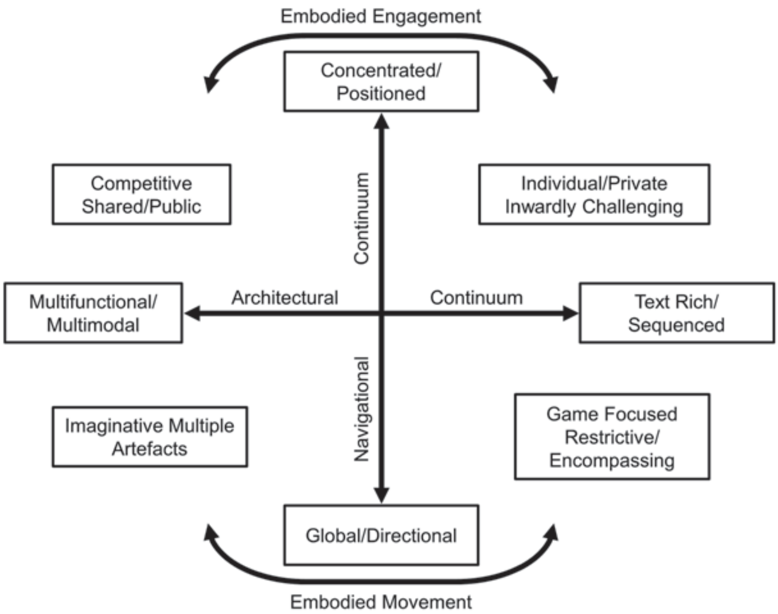


Fig. 8 A model for spatiality and visuospatial reasoning in digital game contexts

The gameplaying model described in this chapter highlights players' preference for engaging with digital games in different ways. The *y* axis presents the gamers' visuospatial preference for interpreting, decoding and encoding spatial features of a game. At one end of the spectrum are players who make decisions from a fixed point or single foci. Typically, these players process spatial tasks in an analytical way that may be fragmented, localised and progress gradually (Lawton 2010). They may also use more landmark navigation, require more environmental cues and follow familiar routes (Wolbers and Hegarty 2010). By contrast, those at the other end of the spectrum tend to be more holistic and global in their spatial connectivity. These players tend to reason in a directional or Euclidean manner, are able to maintain orientation relative to the larger environment, and can be flexible and adaptive in their navigational strategies, requiring fewer cues to remain orientated (Wolbers and Hegarty 2010). The *x* axis describes the architectural continuum of the game design, however attention is given to which aspects of the design particular players are most influenced by. At one end of the spectrum, players focus on text and navigate the game architecture through sequenced steps, in a logical, scaffolded manner. For example, some of the adolescent girls in our study (see Lowrie and Jorgensen 2011) were able to describe the sequencing of movements within a game space in relation to precise details obtained from help boxes and other textual information displayed on screen, with little attention to symbols and icons. At the other extremity, players utilise every available multifunctional and multimodal feature of the game. For example, productive utilisation of two screens or multiple representations of information. For example, games with demanding navigational challenges (e.g., The Legend of Zelda: Phantom Hourglass) can be played on two screens of a Nintendo DS. These multifunctional players tend to access graphic displays in order to monitor their current position in relation to other relevant spaces—the top screen monitors their position in relation to large space (depicted in a bird's eye perspective) and the bottom screen displays more precise movements within a detailed small space. Playing the same game, Profile 1 players tend to ignore the top screen altogether and focus on one screen.

Above and below the *x* and *y* axes are embodied descriptions of gameplay. The embodied context at the top of the model describes the gameplayer's intended persona or disposition. At one end of the spectrum, the player is more focused on extrinsic aspects of gameplay—sharing ideas with friends, discussing strategies, success, and frustrations in cooperative and competitive ways. Gameplaying is public and spatially networked. By contrast, other players have more intrinsic goals, tend to enjoy personal (and private) challenges and tend not to share their experiences with others.

The visuospatial reasoning evoked in these diverse embodied experiences are commonly different. Much more gesturing takes place in the public sphere, with the gameplayers representing space tacitly and directionally. It appears to be the case that gesturing evokes particular types of representations, which may influence how information is processed and how spatial arrangements are acted upon (Alibali 2005). In addition, shared experiences often evoke imagery and visualisation as gamers inform one another on how to progress through levels, find information or move to defeat enemies. Those who tend to play games privately and focus on personal challenges tend to visualise in personal ways. As Bishop (1989) has argued, most visualisation is idiosyncratic in nature so the use of imagery evoked in these situations is by no means limited or restrictive. Nevertheless, the reasoning is different and more likely to be static rather than dynamic—primarily because imagery is not being disrupted by others' voices or representations.

The bottom of the model depicts embodied movement. At one end of the spectrum, gamers access multiple cultural artefacts to enhance the gaming experience. These gamers encounter many visuospatial challenges as they interpret graphs, charts, directional maps and spatial commentary (often on cheat sites or forums) outside of the game space. Spatially, the game console and game are central to the game experience, however other artefacts heighten the game experience—and potentially develop more rich and integrated visuospatial experiences. Other games, and gamers, are centred predominantly around the game itself. Embodied experiences within this sphere tend to be focused on the character and thus the spatial viewpoint is positioned from within the game. Movement is not only game (and console) centric but also bounded within 'inside' space, and therefore movement is established from a fixed point.

The spatiality and visuospatial reasoning model described the manner in which gameplayers utilise spatial abilities and evoke visualisation in game situations. Profile 1 players tend to engage with digital games in the two quadrants on the right-hand side of the *y* axis (see Fig. 8); namely, reasoning in private, inwardly challenging, ways that are focused on the game (and generally only the game). In terms of visuospatial reasoning, these players tend to navigate in a purposeful and logically sequenced manner, evoking imagery in static and framed ways. They tend not to be distracted by visual stimulus and prefer not to utilise multiple representations of data. Their embodied movement in gameplay is generally bounded by the game itself. Profile 2 players fill the two quadrants on the left hand side of the y axis in Fig. 8. These players prefer competitive games, play cooperatively and publicly, and utilise all available artefacts to enhance the game experience. From a visuospatial perspective, navigation is holistic, experiential and multimodal. Visualisation is usually dynamic, flexible and imaginative. These players tend to move between viewpoints and perspectives frequently, in ways that appear chaotic and random. These players are not adverse to risk and tend to consider all data and representations presented to them, especially if they are graphics based. Their embodied movements include substantial time away from the spatial proximity of the game itself.

Conclusion

Mathematics teachers commonly introduce and develop mathematics concepts in isolation. Curriculum documents (and textbooks) typically encourage the introduction of perimeter before areas, and area before volume and surface area. Similarly, 2D shapes are seldom taught in conjunction with 3D shapes despite the obvious benefits of promoting deep learning when related concepts are addressed simultaneously (Bobis et al. 2012). Conceptual building blocks remain fragmented if students do not appreciate that the volume of an object is ‘area × depth’ rather than only ‘length × breadth × depth’. The spatial recognition of shape and object structure is essential for deep understanding and yet multiple representations are rarely sought, sometimes due to the fact that shapes within objects cannot be separated and reconstructed concretely. Such limitations do not exist in digital worlds. Moreover, despite a long history of research that describes the manner in which conceptual development should proceed (2D before 3D or 3D before 2D), it is the case that young children are engaging with multiple representations simultaneously in game contexts.

At times it is challenging to ‘see’ the mathematics in digital games, especially when literacy and graphicacy demands dominant. Nevertheless, visuospatial reasoning is critical to mathematics performance (Wai et al. 2009), and increasingly so in a digital age. Although there are numerous studies that provide insights into why the underlying principles of gaming are so engaging (e.g., Gee 2007) and how they foster motivation and promote deep learning, fewer studies have provided insights into how this transfers into school-based learning.

It appears that gameplaying promotes visuospatial reasoning at several levels or constructs. The gameplaying activity itself promotes both spatial ability and object imagery. From an inside space perspective, the gameplayer mentally rotates objects, decodes graphics, makes sense of multiple representations, discerns between useful and distracting text (and pictures and symbols), and makes decisions about moving within space from an outside space perspective. Visualisation is used to navigate within and between different perspectives, to imagine routes that cannot be seen and way-find through maps and architectures outside of the screen space.

Today's citizens live in a world that is visually demanding, with information being represented pictorially and graphically with more regularity and sophistication. In fact, a global society relies more on core graphic representations than text-based representations. Spatial skills are increasingly necessary to navigate information systems, with information moving from text-based representations to graphic- and text-based representations in order to manage data. Digital games appear to accommodate (and more reasonably replicate) the visuospatial reasoning skills required to interpret and manage information systems than traditional classroom practices and pedagogies. Digital games also allow gamers with different preferences and skills (or game profiles) to access and navigate the spatial demands of information.

References

Alibali, M. W. (2005). Gestures in spatial cognition: Expressing, communicating and thinking about spatial information. *Spatial Cognition and Computation, 5*(4), 307–331.

Arcavi, A. (2003). The role of visual representations in the learning of mathematics. *Educational Studies in Mathematics, 52*(3), 215–241.

Avraamidou, A., Monaghan, J., & Walker, A. (2012). Abstraction through game play. *Technology, Knowledge and Learning, 17*(1–2), 1–21.

Bishop, A. J. (1989). Review of research on visualization in mathematics education. *Focus on Learning Problems in Mathematics, 11*(1), 7–16.

Blazhenkova, O., & Kozhevnikov, M. (2010). Visual-object ability: A new dimension of non-verbal intelligence. *Cognition, 117*(3), 276–301.

Bobis, J., Mulligan, J., & Lowrie, T. (2012). *Mathematics for children: Challenging children to think mathematically* (4th ed.). Frenchs Forest: Pearson Education Australia.

Feng, J., Spence, I., & Pratt, J. (2007). Playing an action video game reduces gender difference in spatial cognition. *Psychological Science, 18*(10), 850–855.

Fernandez-Vara, C., Zagal, J. P., & Mateas, M. (2007). Evolution of spatial configurations in videogames. In S. de Castell & J. Jenson (Eds.), *Worlds in play: International perspectives on digital games research* (pp. 159–168). New York: Peter Lang.

Friel, S. N., Curcio, F. R., & Bright, G. W. (2001). Making sense of graphs: Critical factors influencing comprehension and instructional implications. *Journal for Research in Mathematics Education, 32*(2), 124–158.

Gagnon, D. (1985). Video games and spatial skills: An exploratory study. *Educational Communication and Technology, 33*(4), 263–275.

Gee, J. P. (2007). *What video games have to teach us about learning and literacy* (2nd ed.). Basingstoke: Palgrave McMillian.

Green, S. C., & Bavelier, D. (2006). Effect of action video games on the spatial distribution of visuospatial attention. *Journal of Experimental Psychology: Human Perception and Performance, 32*(6), 1465–1478.

Hegarty, M., & Kozhevnikov, M. (1999). Types of visual-spatial representations and mathematical problem solving. *Journal of Educational Psychology, 91*(4), 684–689.

Hegarty, M., Richardson, A. E., Montello, D. R., Lovelace, K., & Subbiah, I. (2002). Development of a self-report measure of environmental spatial ability. *Intelligence, 30,* 425–447.

Hwang, J., Park, H., Cha, J., & Shin, B. (2008). Effects of object building activities in second life on players' spatial reasoning. In M. Eisenberg, Kinshuk, M. Chang, & R. McGreal (Eds.), *Second IEEE International conference on digital games and intelligent toys based education* (pp. 62–69). Los Alamitos: IEEE Computer Society. doi:http://dx.doi.org/10.1109/DIGITEL.2008.14.

Kalantzis, M., Cope, B., & Harvey, A. (2003). Assessing multiliteracies and the new basics. *Assessment in Education: Principles, Policy & Practice, 10*(1), 15–26.

Kolb, D. A. (1976). *The learning style inventory: Technical manual*. Boston: McBer.

Kress, G. (2009). *Multimodality: Exploring contemporary methods of communication*. New York: Routledge.

Lakoff, G., & Núnez, R. E. (2000). *Where mathematics comes from: How the embodied mind brings mathematics into being*. New York: Basic Books.

Lawton, C. A. (2010). Gender, spatial abilities, and wayfinding. In J. C. Chrisler & D. R. McCreary (Eds.), *Handbook of gender research in psychology* (pp. 317–341). New York: Springer.

Lean, G., & Clements, M. A. (1981). Spatial ability, visual imagery, and mathematics performance. *Educational Studies in Mathematics, 12*(3), 267–299.

Lehrer, R., & Pritchard, C. (2002). Symbolizing space into being. In K. Gravemeijer, R. Lehrer, B. van Oers, & L. Vershaffel (Eds.), *Symbolization modelling and tool use in mathematics education* (pp. 59–86). Dordrecht: Kluwer Academic Publishers.

Lowrie, T. (2005). Problem solving in technology rich contexts: Mathematics sense making in out-of-school environments. *Journal of Mathematical Behavior, 24*(3–4), 275–286.

Lowrie, T. (2011). "If this was real": Tensions between using genuine artefacts and collaborative learning in mathematics tasks. *Research in Mathematics Education, 13*(1), 1–16.

Lowrie, T., & Clancy, S. (2002). Multimodal texts: Numeracy development in naturalistic learning contexts. In *Educational research, risks and dilemmas* (Refereed proceedings of the annual conference of AARE/NZARE). Auckland: NZARE.

Lowrie, T., & Diezmann, C. M. (2009). National numeracy tests: A graphic tells a thousand words. *Australian Journal of Education, 53*(2), 141–158.

Lowrie, T., & Jorgensen, R. (2011). Gender differences in students' mathematics game playing. *Computers and Education, 57*(4), 2244–2248.

Lowrie, T., & Logan, T. (2007). Using spatial skills to interpret maps: Problem solving in realistic contexts. *Australian Primary Mathematics Classroom, 12*(4), 14–19.

McGregor, G. L. (2007). Situations of play: Patterns of spatial use in videogames. In B. Akira (Ed.), *Situated play* (Proceedings of the 2007 Digital Games Research Association conference, pp. 537–545). Tokyo: The University of Tokyo Press. http://www.digra.org/dl/display_html?chid=07312.05363.pdf.

Nintendo. (1998). *Pokémon series* [Games]. Tokyo: Game Freak.

Ramirez, G., Gunderson, E. A., Levine, S. C., & Beilock, S. L. (2012). Spatial anxiety relates to spatial abilities as a function of working memory in children. *The Quarterly Journal of Experimental Psychology, 65*(3), 474–487.

Sefton-Green, J. (2004). Initiation rites: A small boy in a poké-world. In J. Tobin (Ed.), *Pikachu's global adventure: The rise and fall of Pokémon* (pp. 141–164). London: Duke University Press.

Sims, V. K., & Mayer, R. E. (2002). Domain specificity of spatial expertise: The case of video game players. *Applied Cognitive Psychology, 16,* 97–115.

Stieff, M., Ryu, M., Dixon, B., & Hegarty, M. (2012). The role of spatial ability and strategy preference for spatial problem solving in organic chemistry. *Journal of Chemical Education, 89*(7), 854–859.

Tversky, B. (2005). Visuospatial reasoning. In K. J. Holyoak & R. G. Morrison (Eds.), *The Cambridge handbook of thinking and reasoning* (pp. 209–240). New York: Cambridge University Press.

Tversky, B., & Hard, B. M. (2009). Embodied and disembodied cognition: Spatial perspective-taking. *Cognition, 110,* 124–129.

Van Eck, R. (2006). Digital game-based learning: It's not just the digital natives who are restless. *EDUCAUSE Review, 41*(2), 16–30.
van Garderen, D. (2006). Spatial visualization, visual imagery, and mathematical problem solving of students with varying abilities. *Journal of Learning Disabilities, 39,* 496–506.
Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology, 101*(4), 817–835.
Wolbers, T., & Hegarty, M. (2010). What determines our navigational abilities? *Trends in Cognitive Science, 14*(3), 138–146.
Zacks, J. M. (2006). Multiple systems for visuospatial imagery. In *Proceedings of the 28th annual conference of the Cognitive Science Society* (p. 2654). http://csjarchive.cogsci.rpi.edu/Proceedings/2006/docs/p2654.pdf.
Zacks, J. M., & Tversky, B. (2005). Multiple systems for spatial imagery: Transformations of objects and bodies. *Spatial Cognition and Computation, 5*(4), 271–306.

Tom Lowrie is a Centenary Professor at the University of Canberra. Tom has an established international research profile in the discipline area of mathematics education and he has attracted considerable nationally competitive funding from the Australian Research Council. A substantial body of Tom's research is associated with spatial sense, particularly students' use of spatial skills and visual imagery to solve mathematics problems. He also investigates the role and nature of graphics in mathematics assessment. Tom has investigated the extent to which digital technologies impact on the education community including teachers, children, and their parents, as well as children's engagement in out-of-school settings. A particular focus of Tom's work has been on disadvantaged students (particularly Indigenous students and students living in remote areas). He was selected to publish an entry on rural and remote mathematics education in the Springer *Encyclopedia of Mathematics Education* (2014) and is co-author of the book, *Mathematics for Children: Challenging Children to Think Mathematically* (the most widely distributed undergraduate mathematics book in Australia and published in its fourth edition in 2012 by Pearson Australia).

Digital Games and Equity: Implications for Issues of Social Class and Rurality

Robyn Jorgensen (Zevenbergen)

Abstract There has been much written about the digital divide that occurs within the area of computing. Less is known about the possibilities of a digital divide in the gaming context. In this chapter, issues of access and usage among students from low/medium socio-economic backgrounds and students from urban and rural backgrounds are discussed. Particular attention is paid to the amounts and types of usage that the students undertake. While differences were found in the usage patterns on the basis of backgrounds, it was also found that there were very little differences between the types of games that students played. Collectively, these findings offer insights into potential areas for further study and for pedagogy in relation to the use of games in mathematics education.

Keywords Equity · Access · Use of games · Bourdieu · Practice · Habitus · Field · Capital · Gender · SES · Social class · Rural · Urban

There is now a substantial literature on the possibilities of the digital games environment to create new spaces for learning and shaping identities. Views on the potentiality of games are polarized from the argument that games offer new learnings and new learning spaces, through to a position that games are for entertainment with little real possibility for deep learning aligned with the goals of formal schooling. Some of these debates are captured by authors in this book. For example, Lowrie's chapter provides a very strong argument for the possibilities of gaming to create new learning spaces for spatial reasoning. As Lowrie and other authors in this collection have shown, the digital games environment offers a dynamic way of learning and embedding spatial knowledge. Much of the learning of spatial reasoning in schools is through pencil-and-paper work, yet what is very clear from the research in spatial thinking and reasoning is that the digital games environment is very rich in terms of interaction, dynamic representation, as well as offering many spatial concepts in an interesting and engaging format. This then enables young learners

R. Jorgensen (Zevenbergen) (✉)
Faculty of Education, Science, Technology and Mathematics,
University of Canberra, Canberra, Australia
e-mail: robyn.jorgensen@canberra.edu.au

© Springer Science+Business Media Dordrecht 2015
T. Lowrie, R. Jorgensen (Zevenbergen) (eds.), *Digital Games and Mathematics Learning,* Mathematics Education in the Digital Era 4, DOI 10.1007/978-94-017-9517-3_6

to engage with the game and acquire many spatial concepts in meaningful and engaging ways. So if games can offer enhanced opportunities for learning aspects of mathematics, then it becomes important to question who has access to these forms of knowledge and ways of knowing, and what may be the effect of such learning. Since digital technologies have been impacting on educational reforms, there have been concerns raised about such access, often referred to as the 'digital divide', whereby those who have access are more empowered than those who do not have such access. This chapter explores the intersection of three major groups—socio-economic status (SES), geographical location and gender—and their relationship with digital games.

In terms of equity, three key groups in Australia seem to be the most at risk of educational failure—Indigenous students, those of low SES and rural students. The latter two are the key foci for this chapter as the issues related to Indigeneity are many and complex and beyond the scope of this chapter. Drawing on data from three disparate areas—one high-to-middle class; one in a rural location; and one in a very low-SES area, differences in access to digital games is discussed.

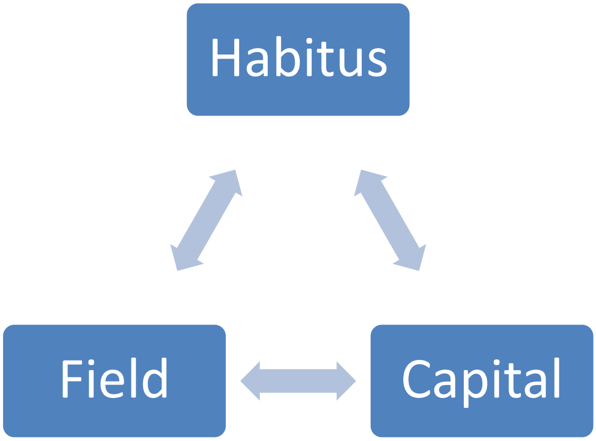
If the literature on the value of the games environment to create new learning opportunities and spaces is valid, then this opens up the possibility for posing questions of who gets access to such learnings, and by implication, who may be marginalized. In this context, this chapter explores the differences between social groups in their gaming practices. Using Bourdieu's theoretical position, I argue that the games environment can be considered a practice through which gamers come to embody particular dispositions. Such dispositions may be cognitive in terms of new learnings but also relate to their sense of self or identity. To this end, the embodiment of these new dispositions helps to shape a habitus, which, in turn, provides a lens for viewing, seeing and acting in the social world. But as with all learnings, some of these have greater value depending on the field in which the learnings are being operationalized. For Bourdieu, these become forms of capital that can be exchanged for goods and rewards within particular contexts. These constructs are expanded in the following section.

Framing Gaming Within a Bourdieuian Lens

Bourdieu's extensive corpus of work provides a strong framing for understanding how gaming offers new ways of shaping learning and learners. His notions of habitus, field and capital allow for a framing, while his notion of practice enables an understanding of the ways in which gaming is enacted to realize, or not, the possibilities of empowerment and exclusion. As illustrated in Fig. 1, there is a strong linking between the three constructs—it is not possible to consider each of them as separate entities.

For example, the field shapes the capital that is valued and hence the habitus, which is the embodiment of culture, may convey power (capital) in some fields but not others. So it is essential within this framing to consider the three constructs

Fig. 1 Theoretical framework



simultaneously. One only has to consider how the games environment may shape the habitus of the learner through the practices to which the players is exposed. Building a games habitus will convey capital in the field of gaming but a key question for educators is whether this habitus and its possibilities for capital will be transferred to the field of education.

In this chapter, what becomes central is how the gaming practices that young learners engage in may shape their habitus. This theorization is akin to the literature on identity formation, but through a Bourdieuian lens, the embodiment of practices becomes habitus formation. In turn, this habitus provides a lens for viewing and acting in the social world (Bourdieu 1981). For Bourdieu, the habitus is a set of durable and transposable dispositions that affords ways of being and acting in the social world, but also allows him/her to change that social world. It is by no means a "conceptual straightjacket" (Giroux 1982, p. 7) but brings about a consistency and coherence within the individual. Here, the practice of gaming may create opportunities for gamers to build a habitus of a particular kind. There is some hope that games environments may also afford opportunities to build the mathematics habitus of learners through engaging with elements, concepts and processes of the games context.

What is important to consider within this framing is the habitus-forming potential of the games environment. Is the envisioned mathematical habitus that educators seek one that has value in out-of-games contexts, such as mathematics classrooms? It is acknowledged by many educators that the gaming environment opens up new possibilities for learning across many areas of schooling—both academically and socially. This is particularly the case for mathematics where both content and processes can be an integral part of many games. By creating new spaces for learners (gamers) to build new forms of mathematical understandings, and where those understandings have value in contexts other than the games context, then gamers may be better able to convert their games mathematics to new forms of power and learning within the school context. This is what Bourdieu has described as the exchange economy (Bourdieu 1977) where goods from one context can be exchanged for others in a different context. In so doing, the goods become forms of capital where they have value in different contexts (Bourdieu 1983). This is most obvious with the games environment where the knowledge and skills (habitus) of the gamer may have considerable value in the games field, but whether these skills have power or are recognized within another field, such as schooling, is questionable. As such, a young player may have considerable accolades bestowed upon him/her by peers or the games environment, but may not have the same esteem in school. Being able to convert the capital in one field (such as gaming) to another (such as schooling) remains a challenge and, indeed, may not even be possible.

The possibility of exchange rests within the practices of the fields (gaming and schooling) and how these practices structure actions and rewards. Indeed, some of the skills may have value within one field and have no value in the other. This is not unreasonable given the mechanisms and valued knowledge within the two fields. However, as an increasing corpus of research indicates, some of the skills and knowledge made possible in the games environment—such as spatial representation—may have considerable value within the context of schools. The complexity made possible through the highly visual representations in the games environments, not only with mapping and visualization but also with data representation, may offer ways of transferring capital gained in the games context to that of schooling.

In my research with young workers (Jorgensen (Zevenbergen) 2009), it was found that estimation skills in the workplace were commonplace and young workers were very adept at estimation. It was theorized that the digital environment created new dispositions (as habitus) for digital natives and that these new skills were being enacted in the workplace. In contrast, most school mathematics contexts focus on accuracy and precision. Similarly, here the gaming habitus may be different from that which is held as important and valued within the school mathematics context. Within this framing, the gaming habitus may not have value, or be transferred as a form of capital, within another context. In contrast, the work of Lowrie (2002) with the Pokémon games environment has illustrated the extension of spatial reasoning that is made possible through these worlds and has value (or capital) within the context of school mathematics. New systems for assessing and incorporating these much deeper understandings may be needed within the school context to enable greater capitalizing of the digital mathematics habitus that young gamers bring to school mathematics.

Much of what is potentially acquired from the games environment has little value or capital within school mathematics. As gamers negotiate their pathways through a particular game they may pay scant attention to the details of numbers but rely more on iconic representations. The attention to many facets of the game means that the gamer pays attention to those details of significance to the potential success within the game. These skills may not transfer to the school mathematics context where accuracy and attention to detail are an important aspect of the context.

Within Bourdieu's framing, what becomes important to consider is how the habitus is both shaped by and helps shape the context in which it is being acquired. The internalization of the habitus results in certain dispositions being developed and that some of these dispositions may convey more or less power (or capital) depending on the context within which they are operationalized. Thus, the skills that the gamer acquires through the gaming environment need to be valued within school mathematics, or over time, the field of mathematics may need to change to recognize and value the skills that gamers possess that help with their mathematical understandings.

Gaming as a Field

Gaming as a field is relatively new but is continually being refined and developed. The games environment offers new ways of looking at and engaging with the social world, and this is being tapped into by games designers to try to crack into new markets, including education. Engagement with digital games is widespread, so much so that many young students have a strong affinity with the environments. Research shows that 97 % of youth aged between 12 and 17 years play video games (Owston 2012); 22 % of American 8–10 year olds visited the Internet on the previous day (Johnson 2011); and 90 % of Australian families have home Internet connectivity (Australian Communications and Media Authority 2007). These figures indicate there is considerable engagement and/or activity among young people in relation to the digital games environment. Attention needs to be turned to the practice in order to better understand its impact and possibilities for learning. How it can be understood and taken up by teachers needs to be better understood (Devlin-Scherer and Sardone 2010).

There is a significant literature on the possibilities of digital games to bring about new learning opportunities and learning environments (see, for example, Ritterfeld et al. 2009). These authors pose questions not only about what children might learn as they engage in/with the digital games environment, but also about new possibilities for games to provide new learning opportunities. So it becomes important not only to consider what mathematics may be learnt in these environments but how the environments are making these new learnings possible. Thus, what needs to be understood better is how these games environments create new opportunities for habitus formation and how these habitus may be differentially acknowledged, rewarded and built into the school mathematics context. While there is substantial evidence that the gaming environment creates new opportunities for literacy learning due to the very changed nature of reading and new textual formats (Gee 2000, 2002), less is well known about the possibilities for mathematics learning.

The new generations of digital games are claimed to provide context where players are able to shape skills and dispositions of collaborators and problem solvers (Singhal 2013). These dispositions, or habitus, are thought to be generated through the need to collaborate with others in order to navigate considerable virtual obstacles in the games environment.

While there are some games that are about ‘school’ learning, many of the games have an action genre to them and often have violent actions incorporated into their design. There is a concern that many of those games with a violent genre may be detrimental to the wellbeing of young people. But such a view is contentious with advocates arguing that there are many good things for gamers to learn as they negotiate their pathways, including violent ones (Ferguson 2010). It has been suggested that games may encourage rather than challenge pro-social behavior (Ferguson and Garza 2011; Kahne et al. 2009). Some research suggests that violent behavior by adolescent gamers is more likely to arise from other characteristics, such as family background, depression or peer delinquency, rather than the violence in the games per se (Ferguson 2011). Thus, the pre-existing habitus is more likely to influence the potential for violence rather than the games.

But there are several games genres that need to be considered including those that encourage activity—exergames. Not only do these games encourage activity with all the associated health benefits but they have also been found to increase self-esteem, social interaction, motivation, attention and visual spatial skills (Staiano and Calvert 2011).

Digital Games and Equity

The digital divide and who gets access to digital technologies has been a long-standing concern among educationalists (Gorski 2009). While a lot of the early work on access, equity and digital technologies focused on digital tools such as computers, its reach needs to extend to new technologies including games and mobile technologies. There needs to be a better understanding if there are issues of equity associated with digital games and who may be better (dis)advantaged by such access.

Gender

When considering equity and the use of digital media and games, there has been a plethora of studies highlighting gendered differences in use and orientation. Some studies have sought to understand how gendered identities are shaped and explored through digital media (Valkenburg et al. 2005). Similarly, there are numerous studies that show the difference in uses of video games and preferences on the basis of gender, where men are more likely to play more frequently, are more experienced and have considerably more confidence with gameplaying than women (Terlecki et al. 2011); and men engaged in achievement-orientated games and were aggressive (Williams et al. 2009). In contrast to adult gamers, there are also clear differences with primary school children in preferences of digital games in terms of genre choice and the time spent playing games (Lowrie and Jorgensen 2011).

Other research has recognized the possibilities of gendered differences and sought to build appropriate digital games for use in curriculum areas in order to engage learners (Beavis 2005). Similarly, other researchers seeking to use games to engage girls in learning raise some of the limitations of such approaches, most notably the creation of a homogenous category of 'girls' (Flanagan 2006).

Social Class

Most commonly, Bourdieu's work is associated with social background so this aspect of equity is most poignant for the framing of this paper. Most of the work in equity as related to SES and digital tools seems to be in the area of computers and Internet access rather than digital games. Through the literature on SES in relation to digital media, there is a consistency in the themes of use and resources, not dissimilar to the patterns found in gender. One common theme is that low-SES families are less likely to have computers in the home or Internet access (Warschauer et al. 2004) than their middle class peers.

It has been found that while there may not be much difference in computer use in the home for young children, the gap between high- and low-SES areas means that access to computers in schools is quite different and so widens the gap between the two social strata as children progress through their schooling (Judge et al. 2004).

Rurality and Digital Games

Rurality is a relative concept and varies from nation to nation. In poor or developing countries, the lifeworlds of rural children is substantially different from that of rural children in Western countries. In work in Indian rural communities (Kam et al. 2009b), it was found that there needed to be particular games designed to cater for the culturally diverse learners in these contexts. Other work conducted with the use of mobile phones and games also supported the general supposition that digital games may offer new means for learning (Kam et al. 2009a) but that there needs to be a recognition of how that learning can be resourced. In the modern or Western countries, where rural education is more related to geographic isolation, issues are more centered around the provision of resources to such sites (Malecki 2003), including the Internet (Mardis 2013; Warren 2007) and, within the context of resourcing, often the focus is on ICTS (Huggins and Izushi 2002). As such, there is little research that explores rural students' use of digital games to support learning.

Digital Games and Their Use by Working-Class and Rural Students

The data that are presented in this chapter are drawn partially from a larger study where urban and rural children were the focus of the research. This paper extends this work through the explicit inclusion of students from a very low-SES community.

Table 1 Distribution of schools

School Type	No. of Schools	No. of Respondents	Mean ICSEA Score
Urban Middle/High-SES	2	187	1038
Urban Low-SES	1	44	909
Rural Varied SES	6	241	980

Students were asked to complete a pencil-and-paper survey detailing their use of digital games in terms of frequency of use, types of games played, types of games preferred, and the mathematics that they thought they used when engaging with the digital games. Students were also asked to list the names of games they preferred. Collectively these responses give a sense of their gaming habits. Students completed the surveys during school hours and all surveys were distributed during lesson times. Schools were identified through their ICSEA scores. (ICSEA is the Index of Community Socio-Educational Advantage, developed by the Australian Curriculum, Assessment and Reporting Authority [ACARA] (2012) to enable comparisons among schools.) The median ICSEA for Australian schools is 1000 with each standard deviation being 100, with the range from 500 (representing extremely disadvantaged) to 1300 (representing very advantaged). The score includes measures of family background (including parental occupation and education levels achieved) as well as language background.

Spread of Schools

Schools were selected on the basis of their demographics to enable access to students likely to come from the nominated backgrounds (Table 1).

Who Participates and How?

From the surveys, a number of analyses were conducted. A one-way ANOVA showed that there were significant differences between the urban low-SES students and the other two groups but little difference between the urban middle/high-SES and rural students, for example, with low-SES students reporting to play significantly more hours than their peers. Students were asked to report against the number of days each week they would play, the hours that they played on school days and then the hours they would play on non-school days.

Gameplaying Habits

To find out the gameplaying habits, students were posed a series of questions that sought to elicit the frequency of playing. These included weekly use, and daily use

Table 2 Weekly usage of games by socio-economic status

School Type	Mean	ANOVA
High SES	2.11	$p > 0.000$
Rural	2.14	
Low SES	2.52	

for school days and non-school days. These questions gave a sense of how the practices of the young gamers may be different or similar and, in so doing, gave a sense of how the gaming habitus may be shaped by their usage.

Using a Tukey post-hoc analysis, it was found that there were significant differences between middle/high-SES students and low-SES students; significant differences between low-SES and rural students; and no differences between middle/high-SES and rural students on all measures of usage. These data suggest that low-SES students' use is different from other students. It was found that low-SES students were consistently more likely to play games more frequently and for longer periods of time than their peers from other SES groups and rural students.

Weekly Usage of Games

To assess regularity of use, it was sought to identify how often the gamers played over a week. The question posed was:

> On average, how many days a week would you play electronic games? (e.g., computer games, handheld electronic games, home gaming consoles).

1. 1 day or less often
2. Between 1–3 days
3. More than 3 days

The results for this were significant, where the students from low-SES backgrounds were more likely to play more frequently than the middle/high-SES peers and their rural peers (Table 2). However, there were no differences between the middle/high-SES students and the rural students. These data suggest that it is likely that many low-SES students are playing more than 3 days per week on gaming systems.

School Days

Students were asked how long they would spend playing games per day on school days. The three options were:

1. Less than 1 h
2. Between 1–3 h
3. More than 3 h

Table 3 Usage by school days

School Type	Mean	ANOVA
High SES	1.39	$p > 0.000$
Rural	1.41	
Low SES	1.93	

The data again suggest that low-SES students were more likely to play games more frequently during school days than their middle/high-SES and rural peers (Table 3). These data suggest that low-SES students are playing up to and sometimes more than 3 h per day while their peers are playing less than and perhaps up to 3 h per day.

Non-School Days

Recognizing that school days may impact on how much gameplaying can be undertaken, students were also asked how often they played games on non-school days. The question posed was:

> On non-school days, how long do you spend playing electronic games per day?
>
> 1. Less than 1 h
> 2. Between 1–3 h
> 3. More than 3 h

Again it is noted that there are significant differences between the low-SES students and their peers from middle/high-SES backgrounds and students in rural areas (Table 4). These data suggest that low-SES students are playing up to and more than 3 h per day of computer games on non-school days.

What these data suggest is that there is differential use of games by students according to social background. While little can be said other than there is a propensity for low-SES students to use games more frequently than their middle-SES peers, it is unclear as to what implications this may have for potential mathematics learning. To this end, it would seem prudent to assess what types of mathematics games may be accessed by young gamers.

Table 4 Usage by non-school days

School Type	Mean	ANOVA
High SES	1.86	$p > 0.000$
Rural	1.89	
Low SES	2.41	

Games and Mathematics

It is recognized that there are a wide range of genres in the games formats. Games that require students to navigate through worlds in their quests are most likely to have considerable demands in spatial reasoning as part of the navigation process. In contrast games that require simulations where choices can impact on the outcomes require different demands from the navigation genre. In these simulations, gamers may need to use problem solving and modeling skills. Many games require gamers to look at various forms of data representations and make interpretations from these graphs, charts or other iconic representations. The broad range of genres and their inherent demands may appeal to gamers in different ways. To ascertain whether or not gamers were using games of particular genres, a series of questions were posed against which the respondents were asked to rate their frequency of use in terms of never, rarely, sometimes, usually and frequently. The questions were:

1. How often do the games you play require you to do maths algorithms or calculations?
2. How often do they require you to read maps?
3. How often do they require you to read graphs?
4. How often do they require you to solve maths problems?

Using a one-way ANOVA and Tukey post-hoc analysis, no statistical differences were found within and between groups in terms of how the students saw the mathematical demands within a game. The mean scores for these items were very low and ranged across all items and all groups from 1.97 and 2.63. These scores suggest that most scores were falling between the "sometimes" and "rarely" range which is low in the rating profile. This is not to say that there were not mathematical demands within the games but that the students did not view the games through this lens.

Similar to findings with the rural and high-SES students (Lowrie and Jorgensen 2011), it was found that the same gendered preferences for games were evident with the low-SES cohort. In this earlier study, games were classified by genre (as noted by the producer of the games). For this aspect of the study, students were asked to note the games that they played and their favorite game. It was found that the low-SES students had similar preferences to the other students. That is, boys tended to play adventure games that have a strong emphasis on mapping skills while the girls had strong preferences for games that required problem solving skills, calculations and interpretations of graphs.

Analysis of Games Preferences

The data presented to date suggest that there are marked differences in the amount of time being played on digital games, with students from working class, or low-SES, backgrounds more likely to engage with playing in the games environment for longer periods of time than players from more advantaged backgrounds and/or their peers in rural contexts.

Table 5 Favorite games preferred by low socio-economic status students

Boys	Girls
COD: Black Ops	Wii games
Halo	Tennis, Sports, Mini Golf
Mario	Moshi Monsters
Pokémon	Toy Story
Assassin's Creed	Just Dance
COD World at War	One Direction
	Smurfs
	Grand Theft Auto
	COD: Black Ops
	Zelda
	LittleBigPlanet
	Style Boutique
	Art Academy
	Farm

Earlier work cited in this paper (Ferguson and Garza 2011) indicated that players can learn considerably more than just gaming skills. In this body of work, social skills and pro-social behaviors can be acquired through games environments. As authors in this collection also show, the games environment offers considerable potential for learning various aspects of mathematics. Collectively, an approach to understanding the potential of digital games to add new forms of capital, particularly mathematical capital, may offer ways to enhance the numeracy/mathematical learning for those students who are most frequently marginalized in the study of mathematics. What becomes important to capitalize upon is the mathematical learning possibilities of the games environment.

The types of games preferred by the low-SES students were quite gendered with the boys preferring action-based/adventure games with quite tight clustering in terms of games preferred. In contrast the girls were quite diverse in their preferences with sports/Wii games being most preferred and many other games being noted as favorites. Gender differences in the use of games have been noted by other authors (Unlusoy et al. 2010) so it is not a new phenomenon. An earlier version of this study, Lowrie and Jorgensen (2011) showed gendered preferences of these games. This study has confirmed that the gendered differences remain consistent across SES groups (Table 5).

What is noteworthy in this study is that there was a very strong emphasis on the use of exercise games being taken up by the girls. Very few boys indicated a preference to Wii games.

In comparing the data from this study with that of the much larger study (Lowrie and Jorgensen 2011), the data from the low-SES students showed no significant differences in games genre preferences. Comparisons were undertaken across the various consoles and the genres/games that students preferred. In either analysis, it was found that there were no noteworthy differences in the preferred games used

Table 6 Games preferences for Wii games consoles

Game	Genre	Percentage Low SES	Percentage Other
Wii Sports	Sport	45.5	61
Just Dance	Party	27.3	
Mario Kart	Action (Racing)	25.0	23.4
Wii Fit	Sport	22.7	25.0
Wii Sports Resort	Sport	11.4	7.5
Mario and Sonic at the Olympic Games	Sport	6.8	7.0
Call of Duty	Action (Shooter)	6.8	
Super Smash Brothers	Action (Fighting)	6.8	7.7
Sonic	Action/Adventure	6.8	
Mario Kart	Racing		23.4
WWII play	Compilation		16.1
Guitar Hero	Party		8.2

by the low-SES students with the urban, middle-SES and rural students. These data suggest that there are no noticeable differences in the preferences of games by the cohorts of students (Table 6).

The percentage of students nominating favorite games for the Wii console indicate that there is a consistency in the games preference and their relative ranking in preference (as evident by the numbers of students who chose the games). The method was a free-call of the games that the students preferred so no prompts were given to the students. This method was seen to not create a bias in the games selections. Similar patterns were observed across the nine consoles nominated in the study.

Conclusions and Implications for Equity

The study was initially based on the belief that there would be marked differences between the low-SES, rural and urban students. It was premised on the general literature on the digital divide and assumed that there would be differences in the use and access to digital games for these cohorts. It was found that there were significant differences in the amount of time that games were played by the low-SES cohort but no other significant differences were found. This suggests that the digital divide in digital games and, hence, the capacity for access and learning is not as obvious in the digital games environment than for other areas of digital technologies (such as computers, Internet, etc.) that have been noted in many other research studies.

By providing greater access to games that have strong mathematical content, then the mathematical habitus of the low SES may be reconstituted to be more aligned with the knowledge and concepts that are valued within the field of mathematics education. In this process, the habitus-building potential of the games environment may be able to reshape the learning of these students and provide them with access to the valued knowledge of the field. As these students noted, they did not see the mathematics embedded within the games they played, although their selections of games indicated that many of them had significant mathematical merit. Being explicit about the embedded mathematics within these games may support stronger learning and access to the dominant and valued forms of knowledge within the field.

In the national testing of numeracy, the school from which the low-SES students were drawn, students performed significantly below the national measures on numeracy but also below in Year 5 and equivalent with similar schools (ACARA 2012). These data suggest that there is a challenge for teaching and learning associated with low-SES students and school mathematics. This is a well-documented correlation so the results for this cohort are hardly surprising. However, what was less well known was the access that low-SES students have to the games environment. Given the longer periods of time that this cohort spends on games, it suggests that the habitus-formation made possible through this medium may offer new pathways for students.

Like other cohorts of students, the low-SES students failed to see the mathematics embedded in the games they played. One easy strategy for teachers would be to articulate and/or draw upon the games environments to build richer and deeper mathematical understandings. Drawing on students' out-of-school experiences has been long recognized as an important bridge between schools and homes to enable deeper meaning making experiences. The rich potential of the games environment may offer exciting links to be made in deep ways for learning of mathematics, particularly for learners from low-SES backgrounds.

References

Australian Communications and Media Authority. (2007). *Media and communications in Australian families*. Report of the Media and Society Research Project. http://www.acma.gov.au/WEB/STANDARD/pc=PC_310893.

Australian Curriculum, Assessment and Reporting Authority [ACARA]. (2012). *Guide to understanding ICSEA*. Melbourne.

Beavis, C. (2005). Pretty good for a girl: Gender, identity and computer games. *DiGRA 2005: Changing Views: Worlds in Play, 2005 International Conference*. http://summit.sfu.ca/item/288. Accessed 26 May 2013.

Bourdieu, P. (1977). The economics of linguistic exchanges. *Social Science Information, 16*(6), 645–668.

Bourdieu, P. (1981). Structures, strategies and the habitus. In C. C. Lemert (Ed.), *French sociology: Rupture and renewal since 1968* (pp. 86–96). New York: Columbia University Press.

Bourdieu, P. (1983). The forms of capital. In J. G. Richardson (Ed.), *Handbook of theory and research for the sociology of education* (pp. 241–258). New York: Greenwood.

Devlin-Scherer, R., & Sardone, N. B. (2010). Digital simulation games for social studies classrooms. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas, 83*(4), 138–144. doi:10.1080/00098651003774836.

Ferguson, C. J. (2010). Blazing angels or resident evil? Can violent video games be a force for good? *Review of General Psychology, 14*(2), 68–81.

Ferguson, C. J. (2011). Video games and youth violence: A prospective analysis in adolescents. *Journal of Youth and Adolescence, 40*(4), 377–391. doi:10.1007/s10964-010-9610-x.

Ferguson, C. J., & Garza, A. (2011). Call of (civic) duty: Action games and civic behavior in a large sample of youth. *Computers in Human Behavior, 27*(2), 770–775.

Flanagan, M. (2006). Making games for social change. *AI & SOCIETY, 20*(4), 493–505. doi:10.1007/s00146-006-0048-3.

Gee, J. P. (2000). Teenagers in new times: A new literacy studies perspective. *Journal of Adolescent and Adult Literacy, 43*(5), 412–420.

Gee, J. P. (2002). New times and new literacies: Themes for a changing world. In B. Cope & M. Kalantzis (Eds.), *Learning for the future: Proceedings of the learning conference* (pp. 3–20). Spetses: Common Ground.

Giroux, H. (1982). Power and resistance in the new sociology of education: Beyond theories of social and cultural reproduction. *Curriculum Perspectives, 2*(3), 1–13.

Gorski, P. C. (2009). Insisting on digital equity: Reframing the dominant discourse on multicultural education and technology. *Urban Education, 44*(3), 348–364. doi:10.1177/0042085908318712.

Huggins, R., & Izushi, H. (2002). The digital divide and ICT learning in rural communities: Examples of good practice service delivery. *Local Economy, 17*(2), 111–122. doi:10.1080/02690940210129870.

Johnson, G. M. (2011). Internet activities and developmental predictors: Gender differences among digital natives. *Journal of Interactive Online Learning, 10*(2), 64–76.

Jorgensen (Zevenbergen), R. (2009). Young workers and their dispositions towards mathematics: Tensions of a mathematical habitus in the retail industry. *Educational Studies in Mathematics, 76*(1), 87–100.

Judge, S., Puckett, K., & Cabuk, B. (2004). Digital equity: New findings from the early childhood longitudinal study. *Journal of Research on Technology in Education, 36*(4), 383–396.

Kahne, J., Middaugh, E., & Evans, C. (2009). *The civic potential of video games*. Massachesetts: Massachusetts Institute of Technology Press.

Kam, M., Kumar, A., Jain, S., Mathur, A., & Canny, J. (2009a). *Improving literacy in rural India: Cellphone games in an after-school program*. Paper presented at the IEEE/ACM Conference on Information and Communication Technology and Development (ICTD), Piscataway: IEEE Press.

Kam, M., Mathur, A., Kumar, A., & Canny, J. (2009b). *Designing digital games for rural children: A study of traditional village games in India*. Paper presented at the proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Boston, MA, USA.

Lowrie, T. (2002). The influence of visual and spatial reasoning in interpreting simulated 3D worlds. *International Journal of Computers for Mathematical Learning, 7*(3), 301–318.

Lowrie, T., & Jorgensen, R. (2011). Gender differences in students' mathematics games playing. *Computers and Education, 57*(4), 2244–2248.

Malecki, E. J. (2003). Digital development in rural areas: Potentials and pitfalls. *Journal of Rural Studies, 19*(2), 201–214.

Mardis, M. A. (2013). What it has or what it does not have? Signposts from US data for rural children's digital access to informal learning. *Learning, Media and Technology*. doi:10.1080/17439884.2013.783595.

Owston, R. D. (2012). Computer games and the quest to find their affordances for learning. *Educational Researcher, 41*(3), 105–106. doi:10.3102/0013189x12439231.

Ritterfeld, U., Cody, M., & Vorderer, P. (Eds.). (2009). *Serious games: Mechanisms and effects*. New York: Routledge.

Singhal, A. (2013). Introduction: Fairy tales to digital games: the rising tide of entertainment education. *Critical Arts: South-North Cultural and Media Studies, 27*(1), 1–8.

Staiano, A. E., & Calvert, S. L. (2011). Exergames for physical education courses: Physical, social, and cognitive benefits. *Child Development Perspectives, 5*(2), 93–98. doi:10.1111/j.1750-8606.2011.00162.x.

Terlecki, M., Brown, J., Harner-Steciw, L., Irvin-Hannum, J., Marchetto-Ryan, N., Ruhl, L., & Wiggins, J. (2011). Sex differences and similarities in video game experience, preferences, and self-efficacy: Implications for the gaming industry. *Current Psychology, 30*(1), 22–33. doi:10.1007/s12144-010-9095-5.

Unlusoy, A., de Haan, M., Leseman, P. M., & van Kruistum, C. (2010). Gender differences in adolescents' out-of-school literacy practices: A multifaceted approach. *Computers and Education, 55*(2), 742–751.

Valkenburg, P. M., Schouten, A. P., & Peter, J. (2005). Adolescents' identity experiments on the Internet. *New Media & Society, 7*(3), 383–402. doi:10.1177/1461444805052282.

Warren, M. (2007). The digital vicious cycle: Links between social disadvantage and digital exclusion in rural areas. *Telecommunications Policy, 31*(6–7), 374–388.

Warschauer, M., Knobel, M., & Stone, L. (2004). Technology and equity in schooling: Deconstructing the digital divide. *Educational Policy, 18*(4), 562–588. doi:10.1177/0895904804266469.

Williams, D., Consalvo, M., Caplan, S., & Yee, N. (2009). Looking for gender: Gender roles and behaviors among online gamers. *Journal of Communication, 59*(4), 700–725.

Robyn Jorgensen (Zevenbergen) is a Professor of Education: Equity and Pedagogy at the University of Canberra. Her work has been focused on issues of equity and access in relation to mathematics education. This work has sought to understand the ways in which mathematics practices are implicated in the success (or not) of students who have been traditionally marginalized in the study of school mathematics. Her work usually draws on the theoretical frameworks offered by French sociologist, Pierre Bourdieu, to better understand the ways in which practices within the field of mathematics education are implicated in the (re)production of equity and inequities.

Multimodal Literacy, Digital Games and Curriculum

Catherine Beavis

Abstract Games are viewed as embodying core principles of good pedagogy and learning, however, it is essential that games are not understood simply as 'learning machines'. Rather, good gameplay is active, socially situated and purposeful, and intimately linked with issues of ownership, commitment and identity. This chapter focuses particularly on the textual dimensions of games and gameplay, within the context of the New Media Age, Multiliteracies and literacy constructed as design, and the ways in which the capacity to read and act upon multimodal literacies enables reasoning and analysis, and the successful progress of play. It takes the example of the citizenship education mobile learning game, Statecraft X, to explore and illustrate matters such as these. It explores and illustrates some of the multimodal forms of reading, literacy and interactions required to make sense of the game, the ways in which doing so enabled students to arrive at new insights and understandings about governance and citizenship, and the kinds of investment, reasoning and assumptions required to do so.

Keywords Computer and video games · Digital games · Games-based learning · Multimodal literacy · Serious games

Introduction

> Reasoning: Students develop an increasingly sophisticated capacity for logical thought and actions, such as analyzing, proving, evaluating, explaining, inferring, justifying and generalizing. Students are reasoning mathematically when they explain their thinking, when they deduce and justify strategies used and conclusions reached, when they adapt the known to the unknown, when they transfer learning from one context to another, when they prove that something is true or false and when they compare and contrast related ideas and explain their choices. (Australian Curriculum, Assessment and Reporting Authority [ACARA] 2013)

C. Beavis (✉)
School of Education and Professional Studies, Griffith University, Gold Coast, Australia
e-mail: c.beavis@griffith.edu.au

© Springer Science+Business Media Dordrecht 2015

T. Lowrie, R. Jorgensen (Zevenbergen) (eds.), *Digital Games and Mathematics Learning,* Mathematics Education in the Digital Era 4, DOI 10.1007/978-94-017-9517-3_7

In a book concerned with digital games and mathematics, this chapter focuses on multimodal literacy and its nature and role in facilitating dimensions of gameplay. It looks specifically at the multimodal forms and symbol systems that collectively create and represent the world in which players play, and the ways in which, in single or multiplayer strategy games, such as Civilization or Statecraft X, the capacity to read, understand and manipulate these systems is central to the complex reasoning processes on which progress in the game relies. The chapter begins by discussing contemporary interest in the potential of digital games to support curricular learning. It provides a brief overview of multimodal literacy and the theory of design, and introduces the Citizenship Education game, Statecraft X, and the principles underlying the design and purpose of the game. From there, the chapter goes on to look at teaching and playing the game in the subject, Study of Society and Education, in a Year 8 classroom in Queensland. It describes the ways in which analyzing, evaluating, inferencing, deduction, adaptation and other forms of reasoning were called upon and enabled as students interpreted and acted upon information presented in the multimodal symbol systems of the game.

Curricular Learning: The Promise and Potential of Games

There is increasing interest in the use of digital games in the classroom, as part of a larger enthusiasm for the potential of games, games' engines and games' design affordances to support learning (Derryberry 2007; Dodlinger 2007; Kankaanranta and Neittaanmaki 2010; Young et al. 2012; New Media Consortium 2012). Where earlier attention focused primarily on video games, and to a lesser extent console games, the last decades have seen an increasing diversity of platforms and technologies available for playing games, and the proliferation of different kinds of games. Games are played on Personal Computers or consoles, and on portable devices ranging from tablets to DS (Dual Screen portable game systems), PSP (Play Station Portables) and phones. In this chapter, the term 'digital games' is used to include but go beyond video games to include games played on these and other platforms, in a wide variety of modes and across a range of genres.

The adoption of digital games in the classroom and growing interest in the possibilities of games to promote learning has sparked considerable research into what constitutes successful games-based learning, and what it might achieve (Young et al. 2012; Perrotta et al. 2013). To be effective, games-based learning needs to be based on good pedagogy and sound learning principles, and to attend to the importance of the social contexts of play. The choice of games to support learning, and the ways they are used, should be informed by a rich understanding of the processes and principles of learning and play and by sound conceptual understandings of disciplinary areas and curriculum and pedagogic priorities. Games themselves need to be chosen and designed to make active use of the attributes or affordances of the form and to capitalize on their capacity to create experiential understandings of complex processes. These include helping players become aware of the interrelationships between multiple elements, and the consequences of one set of actions or choices for another.

A number of factors are called upon to explain the power and attraction of games. These include games' capacity to motivate and engage players, and their potential to match assumed interests, orientations and dispositions towards learning of twenty-first century learners. A related set of qualities are the challenges games offer as "hard fun" (Pappert 2002) and "serious play" (de Castell and Jensen 2003), whereby players are prepared to persist, as games develop complex understandings at increasing levels of difficulty (Gee 2007).

The particular affordances and experiences of play in multimodal virtual worlds offer a different kind of learning than that privileged by content-driven versions of curriculum and transmission model pedagogy. The very nature of games, argues Bogost (2007), means that they prompt increased understanding through the "procedural rhetoric" that structures players' choices, actions and experience as they move through games. de Castell and Jensen argue that knowledge is created differently through playing and making games (de Castell 2011; de Castell and Jensen 2010) through "ludic epistemology"—"a remediated theory of knowledge that asks what knowledge looks like when it's encoded in the form of a game" (de Castell and Jensen 2010, n. p.).

With respect to pedagogy and curriculum, the great strength of games, particularly role-play games, is linked to the ways in which players experience games from the inside. The use of games to support learning needs to recognize the intimate connections that exist between issues of identity, relationships and players' investments in games that occur in good leisure time out-of-school play (Steinkuehler 2006; Chee 2011). Recognizing the importance of the investment of self in games, Chee argues for the design and use of games to create playful and embodied experience and understandings through connections between the games world, performance and identity (Chee 2011). In games-based learning, games design and pedagogy that effectively utilize the affordances of games enables deep conceptual understandings in subject areas.

Multimodal Literacy and the Theory of Design

Games function as an amalgam of text and action (Apperley and Beavis 2013), with both dimensions intimately linked and dependent on each other in order for the game to proceed. While it is misleading to think of games as purely textual, games are quintessentially multimodal forms, combining a wide range of symbol systems in order to be able to be played. Games incorporate image, sound, movement, color, language, symbol, gesture, graphic and spatial representation and more. They require high levels of multimodal literacy from players, including the capacity to identify and attend to a wide range of textual elements and their interrelationships, simultaneously. "Learning about and coming to appreciate interrelations within and across multiple sign systems (images, words, actions, symbols, artifacts, etc.) as a complex system" argues Gee (2007, p. 41), "is core to the learning process". Design, with its double resonance as both noun (the design of the game) and verb (you design a new character), provides a way to think both about the mix of literacies and multimodal symbols that students 'read' on screen, and about the productive component of play where creating is an important part of coming to understand, and making things one's own. Design is central to the kinds of learning prompted and enabled by video games, with good design on the part of the game essential for successful play, and players actively engaged themselves in design, as they interpret and play (Gee 2007). Many of the 'principles of learning', that Gee argues video games exemplify, hinge on the notion of design. These include the 'Active, Critical Learning Principle' where "all aspects of the learning environment (including ways in which the semiotic domain is designed and presented) are set up to encourage active and critical, not passive, learning" (p. 41); the 'Design Principle', where "learning about and coming to appreciate design and design principles is core to the learning experience" (p. 41).

As the metaphor of design makes readily visible, it is what people *do* with the semiotic elements they encounter that creates meaning—that is, semiotic elements go hand in hand with intentions, actions and practice. Reading, viewing, writing, speaking and other forms of communication are active and responsive processes. Literacy works as social practice, serving particular purposes and embedded in real-world contexts. New Literacies scholars highlight the active ways in which literacy works to achieve certain purposes. Literacy practices:

> are what people do with literacy … they also involve values, attitudes, feelings and social relationships … [and include] people's awareness of literacy, constructions of literacy and discourses of literacy, how people talk about and make sense of literacy. These are processes internal to the individual; at the same time, practices are social processes which connect people with one another, and they include shared cognitions represented in ideologies and social identities. (Barton and Hamilton 2000, pp. 8–9)

Citizenship Education and Statecraft X: Gameplay, Learning and Identity

Statecraft X (Fig. 1), designed by Yam San Chee and colleagues at the National Institute of Education, Singapore, is a multiplayer game set in the mythical kingdom of Velar (Chee et al. 2010). The game is played on iPods or iPhones. In teams of five, playing in role as governors of one or more towns in one of four factions, players work through a series of challenges and scenarios as they build up their own towns, conquer others and strengthen these in turn. Initially competing with each other to win the leadership of the kingdom, in the latter part of the game they must work together to defeat an external threat. In doing so, they need to manage their economies and citizenry, including trading with other towns and factions, building infrastructure such as hospitals and barracks, managing citizens' housing, training and employment, together with their health and wellbeing, combat internal

Fig. 1 Statecraft X splash page <http://cheeyamsan.info/NIEprojects/SCX/SCX2.htm>

and external threats, build and use their defence forces, and develop strong and stable societies. Their citizens are a mixed bunch, who must live together harmoniously. No one town has all of the resources required to function effectively—e.g., wood, ore, water, food—so trading is essential. Money is shared between faction members, and cooperation and coordination between faction members is essential to ensure success. The game itself is played outside class time, with teams working together or competing at home or during breaks at school, for those students who do not have broadband access at home.

Specifically designed to take advantage of new media, student experience and “education in the age of new literacies” (Chee 2011, p. 98), Statecraft X is based on a view of learning in which experience is central. Consistent with the observation that games “create new social and cultural worlds—worlds that help us learn by integrating thinking, social interaction, and technology, all in service of doing things we care about” (Shaffer et al. 2005, p. 105), Statecraft X immerses students in a rich imaginative world where they take on roles and responsibilities and follow these through with intensity. Unlike numerous ‘educational’ games, where the aim appears to be on ‘doing school’ and acquiring content more effectively, in Statecraft X, the focus is not on ‘learning about’ but rather, ‘learning to be’ (Chee 2011). Chee’s games—Statecraft X, <http://cheeyamsan.info/GLI_StaticArchive/statecraft-x.html> and Legends of Alkhimia <http://cheeyamsan.info/GLI_StaticArchive/legends-of-alkhimia.html>—seek to capitalize on the affordances and opportunities of massively multiplayer online games to bring about learning of this kind. This enables the development of insider insights and understandings of core processes and concepts at a deep level. Chee cites Thomas and Brown’s 2007 “implicit plea for a shift in pedagogical practice to one that would better leverage the unique affordances of such online gaming environments that might better serve the needs of students today” (2011, p. 98). He draws on Dewey, Mead and Bourdieu to:

> reframe learning … as a process of becoming: a perspective on learning that finds resonance with approaches such as situated learning (Lave and Wenger 1991), communities of practice (Wenger 1998), and discourse as constitutive of becoming (Roth 2010). This reconstruction then allows me to ground game-based learning on the central construct of *performance*, as explicated by the Performance–Play–Dialog Model. (2011, p. 99)

In this, identity is central. So too, is recognition of the out-of-school contexts and characteristics of leisure time play. The narrative structure of the game, the ways in which players are positioned and invited in, and competitive, communicative and collaborative aspects of the game all work to create opportunities for immersion in the narrative fantasy of the game. So too do the circumstances under which the game is played. Echoing 'any time any where' patterns of connectedness and play, gameplay itself takes place in out-of-school time, unconstrained by formal parameters of classroom timeframes, pedagogic structures and agendas, and in tune with when players have the leisure and desire to play.

Teaching and Playing with Statecraft X: Multimodal Literacy and Gameplay

In a Year 8 classroom in South East Queensland, teacher Peter McVeigh called on Statecraft X to teach core concepts in Citizenship Education as part of the Studies of Society and the Environment curriculum. Peter blogged about his experience of the trial run of the game:

> Game play was good. Every 30 mins a new turn would occur allowing students to add to buildings adjust tax rates employ citizens etc. Budgetary constraints were our downfall.
>
> I realized at this point that the game had many benefits that I had not seen in other games. These were:
>
> - Students interacted with each other during the game and outside of the game via messages etc…. I think some of them were face timing as well.
> - Game had a directed structure to it. There were sequenced events planned to occur at specific times to force the player to react. Students would benefit from this as they could explore system changes such as taxation and immigration policies and directly observe the results.
> - Although the game had a directed nature, individual responses to issues were not limited to a single choice. This was beneficial as it allowed great classroom discussion of cause and effect and Cost Benefit of social/political and economical problems.

From the earliest times, it was clear that mathematical considerations—budgetary constraints particularly—were central to the game. The management and allocation of resources, calculations regarding cost and availability, profit and loss, the likely consequence of choices, faced students in every turn. So too did decisions about their priorities as governors. Should they spend money on building up their armies? Educating citizens? Better housing? Social harmony? What would be lost as other areas were advantaged? What could they do? What did they have to do? How would they manage in situations where there seemed to be no choice? As Peter noted, the game “allowed great classroom discussion of cause and effect and Cost Benefit of social/political and economic problems”.

Following the trial, the game was loaded onto iPods, and the iPods given to the Year 8 students in his class. Peter blogged about their response:

> DDay + 1 Students were all excited about the shiny new toys.
> DDAY + 2 I notice clumps of the students in the playgrounds with iPods and serious discussion on how each of them was going to takeover as overlord of the virtual world. Discussion was good; I just need to develop a way to bring it to the classroom for the week’s 2 × 70 min lessons.

The Game went well:

> Newest Blog Entry
> I have now had a chance to run the kids through two lessons.
> Lesson one: I thought that the games experiences were extremely valuable for aiding class discussion.
> Topics
> Lesson One: International Trade: We explore how limited resources and impeded trade between nations/states have the potential to lead to conflict. Used Trade in the 800AD period to illustrate point. Students were able to connect to this idea by drawing on in-game examples. I was surprised at how quickly the kids moved through the discussion as I had delivered this lesson in previous years.
> Lesson Two: Cost Benefit Analysis of Social Systems e.g. medical, social programs etc. The students again worked through this discussion with valuable contributions from a wider range of students than normal. Students again connected the game to the examples that I offered in explanation. This worked very well.

Students could play from home or anywhere where wireless access was possible. The server was on from 6.30 in the morning till 11 pm at night. Thirty-minute breaks between turns provided time for the consequences of moves undertaken during play to become apparent and be put into effect.

Students’ experience of playing the game, and the ways in which through gameplay they gained increased insight into the aspects of citizenship and governance, were centrally linked to the use of textual forms that were small, readily recognizable and full of meaning. Further, it was essential that players had a shared understanding of what these symbols, icons and images referred to and “meant”, as meaning was built through players’ interpretation and engagement with these forms of text. Reading and texts are closely interrelated, with this tight interrelationship integral to play. Textual elements gain in meaning through the practice of being read. Play takes place through a fluid and invisible exchange between symbols, actions and the broad sweep of experience, expectations, paratextual understandings and more that characterize gameplay. In playing Statecraft X students were constantly interpreting the information provided in individual symbols and images, and the patterns created by their juxtaposition. These interpretations formed the basis for understanding and action, and the calculations and reasoning that drove the decisions that they made.

As Kress (2003) notes, the logic of the screen is one where space and simultaneity prevail, unlike the page, where the logic is one of sequence and time. Multiple semiotic systems provide economically coded information on the small screen. The game relies on the use of a range of symbol systems other than words to provide

Fig. 2 Statecraft X running on iPhone: Symbols, numbers and icons <http://cheeyamsan.info/NIEprojects/SCX/SCX2.htm>

information in meaningful and recognizable ways. Wordlessly, the screen presents a clear and economic rendition of the state of the town that is its focus, presenting information in visual form that provides a detailed account of that moment in the overall state of play, with implications for what has gone before and might come after.

The screen in Fig. 2 contains only one ‘word’ (it is in fact an abbreviation of two), but is full of meaning. How is it that students in Peter’s class could gain sophisticated insights into core principles and concepts of citizenship through the experience of play with information presented in almost totally non-verbal ways? What information does the screen provide, and how does it do it?

The screen presents information in numerous ways. Across the top, images functioning as symbols, juxtaposed with numbers, indicate the town population, available stocks of money, water, food, wood and so on—items essential for the welfare of citizens to meet needs as basic as hunger, thirst and the need for shelter. Quantities and components represented call for judgments to be made about the wise use of them to achieve social and political ends—sophisticated decisions to be made, for example, about expenditure, national and international relations and trade. The screen is organized spatially, with different information signaled in different parts. A water tower has been constructed, reflecting the priorities in earlier decisions about expenditure. The water tower, huts, houses and other buildings are located in a schematic but aesthetically pleasing landscape, complete with river, grass and trees. Down the right hand side, a string of what looks like empty circles or buttons are spaces where icons such as hearts or houses also provide important information to the player.

On other screens, space, towns and landscape have their own images, patterns and relationships, with rules governing navigation, travel and arrival, the negotiation of entry, relationships of one town with another, takeovers and so on (Fig. 3).

Fig. 3 Statecraft X running on iPhone: Battle for control of the capital city <http://cheeyamsan.info/NIEprojects/SCX/SCX2.htm>

Other screens, and pop up and drop-down boxes provide further information about citizens, the mix of races, levels of happiness or unrest, the available workforce and so on, while a further set of screens enables messaging between faction members with explanations, requests, bartering and more.

Multiple semiotic streams work simultaneously, across physically diverse locations and networks in synchronous time, with the 30-min timeframe providing mandatory disciplinary parameters during which actions initiated during the previous turn take effect. The literacy practices required to play the game depend crucially on the player's knowledge and capacity to read the multiple and changing patterns of symbol, number, image and so on. It was these practices, these literacies, and the design of the game, coupled with the depth of investment players bring to their roles within the game, that enable the core tenets of Citizenship Education to be lived and experienced firsthand. Students in Peter's class were engaged in a complex set of literacy practices as they played, both individually and as faction members, reading the screens in front of them, juxtaposing information presented in highly abbreviated, visually appealing forms, hypothesizing about what might have happened since they last played, what to do next, and what the effect of the choices they make now might be.

Reasoning, Resources and the Group: Analyzing Gameplay

As the game drew to a close, students in the different factions were interviewed about their experiences, and invited to reflect on their progress, what they had had to do, what they had learnt, and how they felt about it all.

Jim, from the Phoenix faction, described what his group had achieved.

Qu: How are you going so far?

Jim: It's a bit up and down in a lot of situations and times we've gone into debt and sometimes we've had hardly any resources. But we've pulled through in a lot of those situations, and been able to get different resources to other members of the group and been able to help them out of more situations.
Qu: How have you been able to do that?
Jim: Send, do trading offers with them. Send them for example 20 wood for 30 gold or something like that, and also to defend them if they are attacked by military forces. You can send a military force to defend them.
Qu: Do you have an idea about how well your faction is doing relative to others?
Jim: I'm pretty sure we're coming second
Mark: Yeah, we're doing pretty well compared to some other factions. Other factions have had people starve.
Jim: We haven't had many people down like that. Some other factions have been attacked by the neighboring kingdom. Something (I can't remember its name at the moment) but it's coming, and is attacking our kingdom and some people have lost quite a few towns from them.

The relative success of Jim's faction was linked to the group's management of resources and trade, and recognized the interrelationship of trade, income, defence and social wellbeing needed if the faction was to survive. Managing resources was a challenge, but students became rapidly aware of the needs, choices and interrelationships entailed:

Jim: I just tried to keep my people happy by having free health care and we had about three or four people in the healing center. I upgraded them all to level 3.
Qu: Right. That was expensive to do that.
Jim: Yep, but I sold a lot of gemstones so I could do it.
Qu: OK, and you said you were trying to keep them satisfied. How did you do that?
Jim: Well, I noticed my taxes were incredibly high so as soon as I lowered them the happiness was increasing. Then I thought if I keep doing this well, this happiness is going to go up to the happier consumer things so I get some money out of it.
Tom: Yeah, and then we just sell lots of gemstones. Gemstones are a lot of money.

The actions of Jim's group, and his explanation of them, show 'logical thought and actions' just as the ACARA account of 'reasoning' describes—analyzing, evaluating, and evaluating the situation, inferring causes and working out solutions, be that favorable trade where needed, or military defence. Mathematical reasoning is well in evidence in Jim's account of his faction's choices, strategies and success.

Con faced other challenges, but like Jim, analyzed his faction's needs, available resources and governance priorities. His account of how he saw his responsibilities, with respect to the resource he had plenty of (wood), shows mathematical reasoning well in evidence as he recognizes and acts on the consequences of supply and demand, even to the point of his own eventual loss and redundancy.

Con: I had a different environment. It was a lot harder to keep everyone in my town happy, but I had other responsibilities because I was the only person in our faction that began with wood, that could actually build a wood mill so I was having to give wood to most of the people in my faction in order for them to build certain factories and resource industries. So I was very counted on in the beginning, and then I'm not any more. They built their own.

Group members not only understood and correctly interpreted the shifting patterns of images, symbols and icons that emerged after each round of play, and what this meant in relation to the power of individual faction members and towns, they also developed an understanding of how the whole faction was affected and a mind-set that recognized the need to protect faction members and their towns and citizens as a whole. In doing so, they achieved some of the main aims Peter had for introducing the game into the curriculum:

> The big problem doing the civics component [of the SOSE curriculum] is trying to get the kids to think at a higher level. "We should just build the hospital and we should build the roads and everybody should have access to computers and all those types of things"—it's really hard for them to understand it's a resource-driven model…. I was very impressed with the way that kids could draw upon in-game experiences and compare and contrast them against systems within state, systems within countries etcetera. I thought that was a real strength of the game.

The awareness of the need for faction members to work together was also a key factor in the ways in which the winning faction, Griffin, got themselves organized, with "good communication" identified as central from the outset.

> Qu: OK, and so you're the Griffin faction. What was your faction like? How would you describe your faction?
> Caroline: good communication.
> Qu: so, good communication.
> Caroline: Yep.
> QU: What form did your communication take?
> Caroline: for trade and stuff we worked really well because I was the center of it all and everybody knew me, so we had really clear communication lines with each other. Yeah, it was good.
> Anna: We were all friends before the game. There was no danger of someone backstabbing someone else, so if one town was getting attacked, like for example if Kiera's town was getting attacked everyone would quickly gather their armies and defeat the people.
> Qu: Did it work? What happened when you did that?
> Caroline: It worked, we killed some people.
> Qu: So how successful was your faction?
> Caroline: We got the capital city, so...
> Qu: so pretty successful.
> Caroline: Yep.

Caroline took responsibility for overseeing the management of the resources of her team as a whole, creating a book "where I put everyone's names and what they were spending so that we didn't go over a certain amount of money, so that we would still have enough money in case another nation attacked us". Other team members contacted her for advice about whether they could build. She monitored who was playing as turns rolled round—"if someone wasn't playing, trying to communicate with them so they could trade". She stayed up late and woke up early to check what was happening during hours when the server was alive, to ensure the faction stayed ahead of the game. The responsible exercise of judgment, communication, an awareness of the interrelatedness of elements of governance, and the management of trade and resources were intimately linked to social cohesion and prosperity.

Identification and investment in the game were key elements in developing greater insight into core issues and concepts in citizenship education. As Jim described his insights into the experience of governorship "it's different than just reading from a textbook. It actually lets you immerse yourself into the game and into the more knowledge of the game that you're playing and it more engages your brain as to what you're doing". Sam similarly contrasted traditional pedagogy and what he had learnt about the workings of the 'real world':

> It shows there's a very different aspect to it. It's not simply sitting behind a desk simply writing papers or something like that. There's a lot more than that. You've got to be managing a whole bunch of different aspects of life. In the game there was food, water. You had to make sure that there was food and water for the citizens, shelter, military forces and you had to make sure that if bandits or something came to your city that you could protect, I guess that sort of thing. To make sure that your citizens were happy. It's a lot more difficult than you think it would be just starting off playing this game.

What Does it All Mean?

Working with games in school is not easy, and it is important that research into games-based learning acknowledges the messy realities and on-the-ground conditions in schools (Perrotta et al. 2013; Erstad and Sefton-Green 2013). Not all students were equally engaged through the whole process, particularly those whose factions began to lose. While not all students enjoyed the same level of involvement and success, however, the experiences of Jim, Caroline and their teams provide a good illustration of games' possibilities. Peter was keen to use Statecraft X again, in the light of his experience with this group—the most academic stream. He was curious to see how it might go with a more mainstream group and optimistic about the possibilities:

> The level of depth of students' insight was really good. I haven't been able to teach some of those concepts that I've taught at grade 8 levels to the level that I was able to before. Now having said that I want to limit that statement by saying that this was an academic summit class. It would be very interesting to see how a more mainstream class would have picked up on the same things.

The complex understandings and interrelationships that Peter describes rely heavily on mathematical reasoning, enabled by the economic onscreen images and symbols throughout the game, and students' capacities to work with these. It is clear that traditional print literacies and resources will continue to be an important part of school education in the immediate future, and for a considerable time. It is also clear, however, that multimodal, digital literacies and the capacity of well designed digital games to make use of these can enhance and deepen conceptual understandings in subject areas. Students like Jim, Caroline and Sam, at home in the digital world, had no trouble following the interwoven threads and relationships within the game, presented in iconic multimodal form. The nature and affordances of online digital texts, literacies and technologies enable high-level understandings to be gained. While motivation, engagement and 'fun' are the most commonly touted qualities advocated in relation to the classroom use of games, it is the capacities of these new forms of text and literacy, and the affordances of games themselves, particularly the opportunities they offer for personal investment and 'learning how to be', that would seem to offer the most in providing opportunities for students to gain sophisticated disciplinary and process knowledge, in the in-school use of games.

Acknowledgements This work was supported by the Australian Research Council under Linkage Grant LP110200309: *Serious Play: Using digital games in school to promote literacy and learning in the twenty-first century*. Research Team: Catherine Beavis, Michael Dezuani, Joanne O'Mara, Leonie Rowan, Sarah Prestridge, Jason Zagami, Yam San Chee. Research Assistance: Roberta Thompson, Christy McGillivray, Colleen Stieler-Hunt. Particular thanks to Peter, his students, Principal and school, and to Yam San Chee, Liu Qiang, Jason Zagami and Roberta Thompson.

References

Apperley, T., & Beavis, C. (2013). A model for critical games literacy. *E-Learning and Digital Media, 10*(1), 1–12.

Australian Curriculum, Assessment and Reporting Authority [ACARA]. (2013). The Australian Curriculum 7.1: Mathematics. http://www.australiancurriculum.edu.au/mathematics/content-structure. Accessed 23 Jan 2015.

Barton, D., & Hamilton, M. (2000). Literacy practices. In D. Barton, M. Hamilton, & R. Ivanic (Eds.), *Situated literacies: Reading and writing in context*. New York: Routledge.

Bogost, I. (2007). *Persuasive games: The expressive power of videogames*. Cambridge: MIT Press.

Chee, Y. S. (2011). Learning as *becoming* through performance, play, and dialog: A model of game-based learning with the game Legends of Alkhimia. *Digital Culture and Education, 3*(2), 98–122.

Chee, Y. S., Tan, E. M., & Qiang, L. (2010). Statecraft X: Enacting citizenship education using a mobile learning game played on Apple iPhones. In U. Hoppe, R. Pea, & C. C. Liu (Eds.), *Proceedings of the 6th IEEE International Conference on Wireless, Mobile and Ubiquitous Technologies in Education* (pp. 222–224). Los Alamitos: IEEE Computer Society.

de Castell, S. (2011). Ludic epistemology: What game-based learning can teach curriculum studies. *Journal of the Canadian Association for Curriculum Studies, 8*(2), 19–27.

de Castell, S., & Jensen, J. (2003). Serious play. *Curriculum Studies, 35*(6), 649–665.

de Castell, S., & Jensen, J. (2010). Real time playback: Multimodality in virtual worlds. Keynote address, multimodality and learning conference 2010, London Institute of Education, July 6–7, London. Retrieved from http://sites.google.com/a/lkl.ac.uk/cmr/conference-july-2010/keynote-suzanne-de-castells-jennifer-jenson. Accessed 23 Jan 2015.

Derryberry, A. (2007). *Serious games: Online games for learning* (White paper). San Jose: Adobe Systems Incorporation. http://www.adobe.com/resources/elearning/pdfs/serious_games_wp.pdf. Accessed 23 Jan 2015.

Dodlinger, M. J. (2007). Educational video game design: A review of the literature. *Journal of Applied Educational Technology, 4*(1), 21–31.

Erstad, O., & Sefton-Green, J. (2013). Digital disconnect? The 'digital learner' and the school. In O. Erstad & J. Sefton-Green (Eds.), *Identity, community and learning lives in the digital age* (pp. 87–106). New York: Cambridge University Press.

Gee, J. P. (2007). *What video games have to teach us about learning and literacy* (Revised edition). New York: Palgrave Macmillan.

Kankaanranta, M. H., & Neittaanmaki. P. (Eds.). (2010). *Design and use of serious games*. Lexington: Springer.

Kress, G. (2003). *Literacy in the new media age*. London: Routledge.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* New York: Cambridge University Press.

New Media Consortium. (2012). *NMC Horizon Report 2012 K-12 Edition*. http://www.nmc.org/publications/2012-horizon-report-k12. Accessed 23 Jan 2015.

Pappert, S. (2002). Hard fun. *Bangor Daily News, Maine*. http://www.papert.org/articles/HardFun.html. Accessed 23 Jan 2015.

Perrotta, C., Featherstone, G., Aston, H., & Houghton, E. (2013). *Games-based learning: Latest evidence and future directions*. Slough: NFER.

Roth, W.-M. (2010). *Language, learning, context: Talking the talk*. New York: Routledge.

Shaffer, D., Squire, K., Halverson, R., & Gee, J. (2005). Videogames and the future of learning. *Phi Delta Kappan, 87*(2), 102–111.

Steinkuehler, C. (2006). The mangle of play. *Games and Culture, 1*(3), 199–213. doi:10.1177/1555412006290440.

Thomas, D., & Brown, J. S. (2007). The play of imagination: extending the literary mind. *Games and Culture, 2*(2), 140–172. http://www.johnseelybrown.com/playimagination.pdf. Accessed 23 Jan 2015.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity.* New York: Cambridge University Press.

Young, M. F., Slota, S., Cutter, A. B., Jalette, G., Mullin, G., Lai, B., Simeoni, Z., Tran, M., & Yukhymenko, M. (2012). Our princess is in another castle: A review of trends in serious gaming for education. *Review of Educational Research, 82*(1), 61–69. doi:10.3102/0034654312436980.

Catherine Beavis is a Professor of Education in the School of Education and Professional Studies at Griffith University (Australia). She teaches and researches in the areas of English and literacy curriculum, digital culture, young people and new media. Her work has a particular focus on the changing nature of text and literacy, and the implications of young people's experience of the online world for Education. Catherine's research investigates computer games and young people's engagement with them, exploring the ways in which games work as new textual worlds for players, embodying and extending 'new' literate and multimodal literacies and stretching and changing expectations of and orientations towards literacy and learning. Recent research includes Australian Research Council projects: *Serious Play: Using Digital Games in School to Promote Literacy and Learning* (Beavis, Dezuanni, O'Mara, Prestridge, Rowan, Zagami and Chee, 2012–2014) and *Literacy in the Digital World of the Twenty First Century: Learning from Computer Games* (Beavis, Bradford, O'Mara and Walsh, 2007–2009).

Apples and Coconuts: Young Children ‘Kinect-ing’ with Mathematics and Sesame Street

Meagan Rothschild and Caroline C. Williams

Abstract The ability to count objects is a crucial skill for young children. We report on an experimental study that utilized a Kinect Sesame Street TV intervention designed to support two types of counting activities. We conducted quantitative as well as open-coding based analyses, on video data with 3- and 4-year-olds. The complexity of interactive digital media contexts for mathematical learning is unpacked with the assistance of literature from the fields of mathematics education and cognitive science. We conclude by making recommendations for interactive educational design in general.

Keywords Common Core Standards for mathematics · Kindergarten · Microsoft · Kinect · Sesame Street · Embodied cognition · Early education · Number knowledge · Interactive television · Informal learning · Xbox

Introduction

A foundational skill that young children need to develop for mathematics learning is counting. The United States Common Core State Standards for Mathematics Kindergarten standards state that students should learn the number names and count sequence, and be able to count objects (National Governors Association Center for Best Practices 2010). The National Council of Teachers of Mathematics (2000) include in the pre-kindergarten to second grade-band the requirement that all students learn to count with understanding, be able to determine the size of sets of objects, and use numbers to count quantities. Being able to count and connect the counting specifically to specific objects is a crucial part of learning how to mathematize

M. Rothschild (✉)
WIDA, Wisconsin Center for Education and Research, University of Wisconsin-Madison, Madison, WI, USA
e-mail: meagan.rothschild@gmail.com

C. C. Williams
Department of Curriculum and Instruction, Mathematics Education, University of Wisconsin-Madison, Madison, WI, USA
e-mail: caro.williams@gmail.com

© Springer Science+Business Media Dordrecht 2015
T. Lowrie, R. Jorgensen (Zevenbergen) (eds.), *Digital Games and Mathematics Learning*, Mathematics Education in the Digital Era 4, DOI 10.1007/978-94-017-9517-3_8

the world, as well as to continue in further mathematics learning trajectories. This project focuses specifically on supporting 3- and 4-year-old children in counting by using a Sesame Street episode made interactive through the medium of the Microsoft Kinect 2012, a motion capture device for the Xbox console. In the following section, we briefly review literature on video games and learning, and on embodied cognition and mathematics. We then further describe the relationship between the Kinect and Sesame Street, before transitioning to describe our study design, implementation, and analysis.

Considerably varied research indicates that video games can be powerful vessels for learning (Barab et al. 2010; Fisch et al. 2011; Gee 2003; Squire 2011; Steinkuehler and Duncan 2008). By leveraging some elements of video game design and transforming the traditionally televised one-way information flow into an interactive learning experience, the Sesame Street Kinect series has the potential to increase the engagement and learning of its participants. In particular, this multimodal design aligns with embodied cognition research that suggests that cognition and action are intertwined (Shapiro 2011). Theories of embodied cognition contend that thinking and learning are not based on amodal symbol systems, but rather are inextricably woven into action and perception systems (Barsalou 1999, 2008). Researchers examining the relationship of action and gesture to mathematics learning have found promising results (Alibali and Goldin-Meadow 1993; Glenberg et al. 2007a; Nathan et al. 1992), including interventions in which actions and gestures are designed to be related to successful solving of specific conjectures (Dogan et al. 2013; Walkington et al. 2012, 2013). In summary, physical action can influence mathematical cognition and, consequently, using the Kinect in conjunction with episodes designed to support mathematical learning may leverage action as a way to support cognition.

The questions about the nature of learning with Kinect Sesame Street TV led to a research project conducted at Microsoft Studios in which the first author began to investigate the nature of participant experiences in two-way episodes and traditional television episode viewing. Two interconnected questions formed the focus of the project: How are mathematical concepts learned in each context, and how may interactivity relate to concept learning? The episode follows Sesame Street's emphasis on literacy and STEM; it includes a word of the day, a number of the day, and—to connect to the interactive elements—a move of the day. The internal white paper produced as a result of the initial analysis of the study (Rothschild, internal Microsoft white paper 2012) presents preliminary results showing all students that watched the episode (both experimental and comparison groups) showed statistically significant learning gains when all the tests were collapsed. This included assessment items related to letter recognition, relational concepts, and number knowledge. Initial analysis of the assessment total did not, however, demonstrate a statistically significant difference by condition or gender. A review of observational notes and engagement data indicates that there may be more nuanced issues to explore within the data set in order to more deeply understand the experiences of participants engaging with the episode and related assessment. This paper uses the data collected in the earlier study conducted at Microsoft, and goes deeper into a quantitative and qualitative analysis of the questions specifically related to number knowledge, and presents the investigation of the number knowledge component of the episode studied within the frames of current math education and cognition research.

Sesame Street and Kinect Television

Research and position papers by leading early education organizations recognize that varied media use is becoming ubiquitous in early childhood, and when used within developmentally appropriate frameworks, can effectively promote learning and development for young children (National Association for the Education of Young Children [NAEYC] and Fred Rogers Center for Early Learning and Children's Media 2012). Sesame Street is a proven television format with an extended media legacy of success. The format has been shown to produce learning gains in younger viewers across studies over the last 43 years, including a longitudinal study that supports the findings of learning gains (Ball and Bogatz 1970; Bogatz and Ball 1971; Fisch and Truglio 2001). Additional studies suggest that as children form parasocial relationships with the characters in the Sesame Street narrative world, they are more apt to learn targeted video content (Lauricella et al. 2011). The Sesame Street Workshop leverages multiple media to extend educational content and play-based connections to the Sesame Street narrative world, including web-based games and resources, character toys, and video game console products.

In 2010, Microsoft Studios released the Kinect, an Xbox peripheral device for motion-sensing input. Since the release, Microsoft has worked on ways to engage audiences beyond their traditional core gamer, producing titles like Dance Central, Kinect Sports, Disneyland Adventures, and Nike+ Kinect Training in order to engage kids and families. Using the Kinect, participants are not bound in their play experience by holding a controller, as the Kinect peripheral device uses gesture, facial, and voice recognition that turns the player's body and physical participation into the controlling agent. Among the products that Microsoft has released to push the boundaries of traditional gaming and television viewing experiences is Kinect TV (2012), featuring initial product lines that include a uniquely developed set of Sesame Street and National Geographic interactive television episodes.

For the developers of Kinect Sesame Street TV, the goal was to extend an already successful media property and viewing format. The designers wanted to design their products based on firm research, in order to make sure that the added Kinect interactivity would not adversely disrupt the potential for learning gains found in the linear television format (Rothschild, internal Microsoft white paper 2012). This included understanding situated learning theory and the role of learning in the context of relevant activity (Gee 2003; Barsalou et al. 2003), as well as scrutinizing the potential learning through a lens of embodied cognition, connecting concepts to a learner's own perceptions—which includes relationships between the content and themselves/their own bodies (Glenberg et al. 2007a, b).

Informal Mathematical Learning

Cross et al. (2009) note that while young children are capable of becoming competent in mathematics, a lack of appropriate formal instruction or informal opportunities in the home or community often prevents the learning of foundational concepts. The authors go on to recommend two areas of focus, Number as well as Geometry and Measurement, and further suggest that one way to remedy suboptimal learning situations is to provide various informal opportunities for learning mathematics outside of school. Baroody et al. (2005) further suggest that informal mathematical learning is a key part of successful trajectories in learning mathematics, specifically for developing number sense in young children. Consequently, the Kinect Sesame Street TV episode format is poised to fit this gap by providing content-driven informal opportunities to engage in mathematical learning.

The Number Core

The mathematics included in the study design and assessment involve what Cross et al. (2009) call the 'number core', in this case by modeling and asking participants to coordinate cardinality, the number word list, and one-to-one counting correspondences. They define each as following: cardinality involves perceptual or conceptual subitizing; the number word list involves knowing the order of number words (i.e., 1, 2, 3, …); and one-to-one correspondences requires matching the two such that, for example, each object being counted requires one and only one number word in the appropriate list order. Cross et al. (2009) note that practicing all three of these activities, as well as coordinating between them, will improve the ability of young children to be successful—for example, 2- and 3-year-old children are considerably more likely to be able to count five objects successfully if they have had repeated practice at this task. The methodology, reported in the next section, was designed specifically to support repeated practice, and the open-coding analysis, reported later in this paper, found subitizing, the number word list, and one-to-one correspondences to be an integral part of understanding the results.

Methods

This chapter analyzes data that was collected in an earlier study that took place at Microsoft, led by the first author. Forty-two 3- and 4-year-olds participated in the study. The group was composed of a mix of boys and girls from Seattle and its surrounding areas. The requirements for participant families were that they needed to have regular access to an Xbox 360 and Kinect in their home, that they had not previously viewed the episodes, and that the child was proficient in English. Data was collected at the Microsoft User Research Labs, and consisted of video footage, observation notes, pre-tests and post-tests, and parent surveys (including demographic data). Participants were divided into two groups of 21 by a process of stratified random sampling, accounting for gender and known family annual income. One group of participants was designated as the KINECT group, in which Kinect Sesame Street TV experiences took place as designed with all interactions on. The other group was the TRADITIONAL group, in which interactions were still elicited but the episode did not require interactions to progress. In other words, the participant experienced the same content but edited to a non-interactive, linear format.

Participants came in to the research lab with a parent or caregiver, and participated in a pre-test, watched the episode, then completed a mid-test. The child and guardian left the lab with a copy of the episode in the format that they viewed (KINECT or TRADITIONAL) and then played the same episode at home over the next couple weeks. Parents logged their child's play and made observations. The child and a parent or guardian returned to the lab one more time to view the episode and then participate in a post-test. For the purposes of this paper, analysis is specifically targeting the questions regarding the number five (the number of the day for the episode), and comparing pre- and post-test scores, with mid-test scores used to interpret the open-coding analysis. The nature of these tests will be discussed in detail in a later section.

Number Knowledge in the Episode

In the episode, the scene opens with Cookie Monster dropping a banana peel on the ground, which a bustling Grover then slips on, dropping his delivery of five coconuts. Grover then asks the audience member to please help him collect his five coconuts by throwing them into his box. For each throw, an image of the box is displayed with a visual of how many coconuts are now in the box. The number of coconuts in the box is displayed in the lower right corner of the box (see Fig. 1). Grover states, "Now I have (*number*) coconuts in the box." At the end, the box with five coconuts and the number five in the bottom right corner is displayed as Grover cheers, "Hooray! Now I have FIVE coconuts!" In the KINECT group, when the participants threw, the Kinect motion sensor would respond to their movement in the system, and the coconut would fly into the screen and into Grover's box, sometimes in silly and surprising ways (see Fig. 2). If the child did not throw the coconut, Cookie Monster would come into the scene having 'found' one, and drop it into Grover's box. Grover would then ask the audience member to try throwing the next one. The TRADITIONAL group would get the verbal prompts from Grover to throw the coconut, however, their activity did not affect the way the show progressed, and for each coconut, the show would progress as if the child had made a successful throw.

Fig. 1 Throwing coconuts into Grover's box

The Performance Assessment

Games, interactive media, and playful learning are taking a prominent role in educational dialogue. Consequently, the issue of assessing these media must be raised. For early learners, design foundations should meet Developmentally Appropriate Practice (DAP), articulated by the National Association for the Education of Young Children (NAEYC). The 2009 policy statement describes the ways that knowledge

Fig. 2 Participant throwing coconut

of child development and learning and methods that are adaptive and responsive to individual children should be linked to social and cultural contexts of a child's life. DAP contends that the domains of development and learning are interrelated. Understanding child development, trajectories of learning, and the contexts of media and play for learning became paramount in the development of the assessment activities for this research.

The assessment activities were designed to feel playful and both match the spirit of the episode and align with the sorts of performance elicited in the show. Because the study that took place at Microsoft was a pilot study for Kinect Two-Way TV, the net cast in the research was wide and would encompass a broad variety of participants with a multitude of media and learning contexts, from home languages other than English to specific behavioral needs, to experiences with media and the narrative world of Sesame Street. This meant that the assessment tasks needed to be designed to allow a variety of levels of conceptual knowledge to be demonstrated. The protocol needed to remain reflexive to the behaviors and abilities of an individual child, particularly given the long time period of each study session (a 40-min episode and time for assessment activities). In addition, the move from a visual TV format of participation to a paper and analog manipulative format of assessment represented a shift in modality. Thus the characters and playful nature of episode activity were important for connecting the episode's learning stimulus to the assessment performance activities. The activities related to letter recognition, number knowledge, and relational concepts were designed to include participant feedback and decision-making in the hopes of increasing participant agency in the activities without detracting from the ability to elicit specific modes of content knowledge demonstration.

Because this new analysis focuses on the nuances of the mathematical activities, this chapter will describe number knowledge assessment items in details. The researcher began by asking the participant to pretend with her, imagining that they had been walking through an apple farm together (situating the activity). The researcher said, "Oh look! We found some apples on the ground!" and displayed a page with five apples on it (see Fig. 3). The researcher then asked, "Can you count how many apples we found?" and, if needed, prompted with "Point to and count each apple that you see". If the child counted to five, it was initially coded as correct; anything other than counting exactly to five was initially coded as incorrect.

Immediately following the Enumeration activity, the researcher segued into the Number Application activity by telling the child that Cookie Monster loves apples, and that today they were going to help him cook. The participant helped decide what should be cooked (e.g., apple cookies, apple cake, applesauce), further situating the activity with recognizable characters from the episode and providing the participant with an opportunity to determine elements of the assessment narrative. The researcher brought out a bowl, seven foam core apples, and an image of Cookie Monster, placing them in front of the child (see Fig. 4).

The researcher then told the participant that Cookie Monster needed exactly five apples to make his recipe, and asked, "Can you put five apples in Cookie Monster's

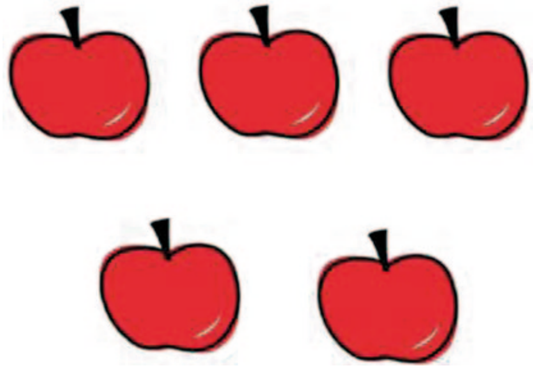


Fig. 3 Enumeration activity

bowl?" If the participant placed five apples in the bowl, it was initially coded as correct. Anything other than five apples in the bowl was initially coded as incorrect.

The goal of these two activities was to provide the child with avenues to convey a range of number knowledge abilities. Enumeration was most directly modeled in the episode, and matched a developmentally appropriate benchmark for 3- and 4-year-olds. The second activity, counting apples for Cookie Monster's recipe, deviated from the episode. In the episode, there was no way in the interactive system to miscount—the activity was physically tied to throwing five and only five coconuts. The designed interactive system limited the participant to throwing or not throwing, and did not support actively applying number knowledge to a situation and receiving corresponding feedback. However, understanding the depth of the participants' understanding of the number five required an assessment inquiry of more than enumeration ability.

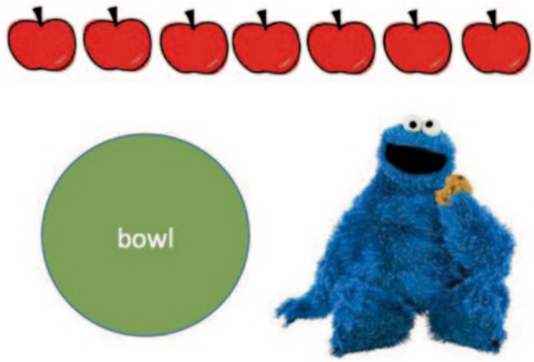


Fig. 4 Number Application activity

Results

In this section, we share the results we anticipated, and then share the actual empiric results. We then explore the data using qualitative open-coding in order to further understand the quantitative results. We conclude by making recommendations to the researchers and designers interested in interactive digital learning experiences, in order to give insight into designs that more deeply support the desired types of learning.

Expected Results

As a consequence of playing the Sesame Street episode, and due to the general benefit of this intervention discovered in Rothschild’s internal white paper (internal Microsoft communication 2012), we expected the children to improve in their ability to count to five, which requires attending to cardinality, the number word list, and one-to-one correspondences. Based on the existing success of the Sesame Street platform and the earlier preliminary results of the overall assessment (Rothschild, internal Microsoft communication 2012), we theorized that both groups would show learning gains, with the possibility of the KINECT group showing greater gain due to increased activity and engagement.

Empiric Results

The actual results did not unilaterally fulfill our expectations. Regarding our hypothesis that the KINECT group would perform better than the TRADITIONAL group, no significant difference was found between the two conditions according to Fisher’s Exact Test for the Enumeration ($p > 0.05$) or the Number Application ($p > 0.05$) tasks. Furthermore, no significant difference was found when the conditions were collapsed ($p > 0.05$). However, the results of our qualitative analyses align quite well with literature on child development and mathematics learning, and suggest that the lack of significance is due to considerably different reasons for each test. (Because of the lack of statistical differences between the conditions for this intervention, we collapse the conditions for the remainder of this chapter).

For the Enumeration test, 38 children contributed complete data to our analysis. Of those 38 children, 28 were successful in enumerating five apples during the pre-test, indicating that counting to five was a skill that these participants were already quite competent at. At post-test, 32 participants were successful (which included all 28 who replied accurately during the pre-test). Given that nearly 75 % of participants came into the study with the target skill, it is hardly unexpected that a ceiling effect occurred.

The Number Application test, on the other hand, suffered from no ceiling effect but similarly demonstrated few gains. Sixteen of the 38 participants were successful during the pre-test, and only 20 were successful during the post-test (again, all the participants who performed correctly during the pre-test continued to be correct in their post-test). Intriguingly, as an exact but nonverbal task, this performance assessment appears to be quite achievable, even for participants of this age (e.g., Baroody et al. 2006), so the study did not accidentally include a task with achievable content but overly challenging performance demands (as Gelman and Meck 1983 so eloquently warn us about). Consequently, we more deeply examined the data qualitatively to determine exactly why there were no significant results.

Open-Coding Analysis

We analyzed the video data of each participant by coding each action undertaken. Since each participant was assessed three times (before encountering the intervention, after encountering the intervention once, and after encountering the intervention multiple times), we analyzed each of the two tasks during each of the three performance assessments per participant. If three or more of the six data points per participant were absent, the participant was dropped from this analysis, leaving a total of 35 participants from the original 43. Our coding schemes were emergent, achieved through open-coding the participants' actions and merging similar codes into several core codes, presented in Tables 1 and 2. The schemes are structurally quite different, as the Enumeration coding scheme is built of categories, while the Number Application coding scheme has multiple codes which are applied in a concatenated fashion.

The codes for the Enumeration task (Table 1) are applied singly, except for the (*circuitous*) code, which is appended to the primary code when appropriate. The codes for the application task (Table 2) are broken down further than the codes for the enumerating task (Table 1), due to the increased complexity of the concept under examination. The physical process of moving the apples to the bowl is labeled as conducted in a sequential or grouping fashion, and appended to this code is whether the participant counted aloud (verbal or nonverbal) and whether the participant is correct or incorrect. The NOTHING code, used in both the Enumeration and Number Application tasks, is used during analysis as though data were absent.

Following the completion of coding, an additional round of open-coding was conducted that built upon the patterns observed by each participant. For example, the majority of participants were already adept at the Enumeration task at pre-test (25 of the 35 in this analysis), and those who demonstrated their proficiency at all three assessments were coding more broadly as "All Correct—No Change." A similar code was also applied to the smaller number of participants who were always able to perform correctly during the Number Application task (13 out of the 35)—and in both cases, the *method* with which each participant showed their knowledge was irrelevant to our needs. They came to the intervention knowing how to count,

Table 1 Enumeration codes and definitions

Enumeration Code	Enumeration Code Definition
One-to-one counting correspondence	The participant sequentially touches the apples (or points at them) while verbally following the appropriate number word list, and concludes with the accurate count of 'five'
One-to-one counting correspondence—no movement	The participant verbally follows the appropriate number word list, but does not physically touch nor gesture towards the apples
One-to-one counting correspondence over-counts to x	The participant sequentially touches the apples while verbally following the appropriate number word list, but over- or under-counts to x
One-to-one counting correspondence Subsets (x, y)	The participant sequentially touches the apples while verbally following the appropriate number word list, but divides the set into two subsets of x and y while counting. The most frequent occurrence of this code included the subsets of 2 and 3, likely due to the visual stimuli layout (see Fig. 3)
Nonverbal enumeration to x	Participant does not verbally enumerate, but concludes by stating the number x
Without accurate number word list (x, y)	The participant follows an incorrect number word list, and ends the count with the number x, after speaking y number words in some order
With accurate number word list (x, y)	The participant follows the correct number word list, but ends the count with the number word of x, putting y objects under a single number word
(Circuitous)	This is a subcode, appended to the previous codes, merely to indicate that the participant does not follow a path that makes it easy to remember which numbers have already been counted. For example, most correct participants follow a 'loop' while they're counting; but participants who received this subcode may have followed, for example, a 'W' shape on the stimuli (see Fig. 3)
NOTHING	Participant says and does nothing, or refuses to cooperate

Table 2 Number Application codes, types, and definitions

Application Code	Code Type	Application Code Definition
Sequential	Apple Movement	The participant placed the apples in the bowl in a sequential fashion, one by one
Grouping	Apple Movement	The participant grouped the apples in some fashion before placing them in the bowl. Primary types of grouping included moving apples into clumps on the ground, and placing more than one apple in their hand at once
Verbal(x)	Communication	The participant speaks the number word list out loud, correctly or incorrectly. The x refers to how many number words were spoken in total
Nonverbal	Communication	The participant does not speak while completing the assessment
_Correct	Solution	Participant accurately placed exactly five apples in the bowl
_x	Solution	Participant placed a number of apples other than five in the bowl, with a total of x placed
NOTHING		Participant says and does nothing, or refuses to cooperate

and they left in the same condition. (And, unsurprisingly, the same 13 who were consistently successful at the Number Application task were also always accurate at the Enumeration task.)

Once the "All Correct—No Change" participants in the Enumeration task were removed, additional patterns emerged, but with the weakness one expects when over 70 % of the participants are absent. Of the remaining nine participants, three showed no consistent improvement, four improved in their ability to perform one-to-one correspondences, one became more accurate in her use of the number word list and one-to-one correspondences, and two appeared to become worse.

Thankfully, once the "All Correct—No Change" participants in the Number Application task were removed, a more interesting pattern emerged among the 22 participants remaining. A full 14 of those participants (64 %; 40 % of total) did not deviate from their initial response, doing the exact same action during the pre-test, mid-test, and post-test: placing all seven of the foam core apples in the bowl. We termed this the "All the Objects" rule, and unlike the "All Correct—No Change" participants, the "All the Objects" participants showed a wide variety of abilities, strategies, and trajectories in their Enumeration task performances, perhaps signifying that the "All the Objects" solution method is a particularly sticky one that requires deeper understanding than Cross et al.'s (2009) number core. Lastly, of the remaining eight participants in this grouping, two showed no improvement (but did not consistently put all seven apples in the bowl), two appeared to worsen, and the remaining four improved.

Discussion

As 40 % of the participants used the "All the Apples" strategy to complete the Number Application task, and varied widely in their ability to succeed in the Enumeration task, some skill or level of conceptual understanding appears to be missing. Upon first glance, the two tasks seem quite similar: in both, you are asked to count five apples. Upon further reflection, however, the Number Application task requires that the participant carve out a subset of five apples from a set of seven—which was only partially modeled by the intervention. For example, the intervention modeled that every time a coconut is added to the box, the number of coconuts in the box goes up by one (e.g., the intervention gently focuses on the impact of the addition to the group). However, the intervention does not model the division of a set into subsets (e.g., how the whole can be separated into new wholes). Consequently, whether the 40 % of participants are not grasping the mathematical concept or whether they are merely following the social training of the episode (i.e., putting *all* the coconuts in Grover's box), is difficult to tell.

Given that carving out five apples from seven appears to be so difficult, we became interested in the few participants who used a grouping strategy prior to putting the apples into the bowl. (However, as the number of participants using grouping is so small, we include this in the Discussion section as a thought-provoking mention instead of in Analysis as a more significant finding.) Since some participants would use a grouping strategy during one assessment and a sequential strategy during the next, we broke up the assessments into individual 'clips', so that they stood alone (for example, Participant T001 is now broken up into T001Pretest, T001Midtest, and T001Postest, and grain size is now the clip). This resulted in a total of 105 clips, and of those, 87 were coded as sequential, while merely 18 were coded as grouping. The sequential clips had approximately a 40 % chance of being correct—while the grouping clips, remarkably, had approximately an 82 % of being correct! We do not have the data to conclude whether children who grouped were more successful because of the strategy, or because they knew more (and consequently knew to use the grouping strategy), but a possible next direction for teaching young children mathematics in this multimodal context would be to have the grouping strategy specifically modeled for them on screen in some fashion.

As a brief note prior to concluding the Discussion section, the children who became worse are particularly interesting, but unfortunately too few in number to glean much from. We tentatively hypothesize that they were attempting to adjust their strategies, not knowing *why* their strategies were wrong but knowing that they were, and adjusted them in the incorrect direction.

Conclusion

The interactive media industry is saturated with products and applications targeting basic math and literacy skills for early childhood. A strong conceptual foundation requires that children have the ability to move from basic knowledge to content application. This analysis shows that for an older preschool target audience, interactive media developers would be well advised to move beyond enumeration activities and look into supporting the transition from enumeration to number application. Additionally, this analysis shows that what may appear (particularly to adults) to be a simple cognitive progression may be riddled with complexities for a young child who is learning higher order number sense. Interactive media tools hold promise for providing meaningful learning experiences for children, but the complex nuances of learning, particularly in mathematics education, may require specific forms of scaffolding, like that suggested above. While it is quite simple to merely discard results that, like ours, show no significant difference between pre- and post-tests, it is through more qualitative analyses that we—as members of many fields interested in similar design and research—can unpack the complications of learning and design more powerful interactive educational opportunities.

Our design recommendations are broad and go beyond the scope of this particular study. It is quite easy to examine the findings of the second performance assessment and make particular design recommendations. For example, based on the literature cited above, the finding that participants struggled to count five apples into the bowl is not surprising—and fixing it may be as simple as re-designing the intervention slightly, so that it involves Grover and—for example—Elmo. If Grover and Elmo were both carrying boxes of coconuts and ran into each other on the screen, scattering the coconuts, and required the participant to place five coconuts in Grover's box and two coconuts in Elmo's box, the participant could begin understanding how a single set of seven objects could be broken up into five objects and two objects. Naturally, this recommendation needs empirical testing! Consequently, we go beyond this local recommendation and instead venture to make some recommendations for the field as a whole.

The results here indicate that while there were not significant learning gains between the pre- and post-mathematics assessments, our more qualitative analysis reveals intriguing findings that can be explained in part by existing research in mathematics education and cognition. Our ongoing analysis examines the demonstrative behaviors of the study participants as they perform the required activities of the number knowledge assessment items. While this can provide the researchers with a deeper understanding of both participant engagement with a situated learning activity and the nuanced methods in which early learners demonstrate their knowledge of specific content, the suggestions for interactive media development proposed still stand. Interactive media is poised to dramatically change the field of learning, especially when pairing newly emerged technologies like the Kinect with tried-and-true educational interventions like Sesame Street. The results that are most useful for designers and mathematics educators, however, may be hiding behind a simple test that declares discouragingly: "No significant differences."

Acknowledgments We would like to thank Alex Games of Microsoft Studios and Rane Johnson of Microsoft Research for supporting the research that led to these findings, and Jordan T. Thevenow-Harrison of the University of Wisconsin-Madison for his invaluable statistical assistance. Finally, thanks to our advisors and mentors who made this research and analysis possible: Drs. Kurt Squire, Constance Steinkuehler, and Amy B. Ellis. Earlier versions of this paper were published in the Games+Learning+Society 9.0 conference proceedings (Rothschild et al. 2013a) and in the Psychology of Mathematics Education—North American chapter proceedings (Rothschild et al. 2013b).

References

Alibali, M. W., & Goldin-Meadow, S. (1993). Gesture-speech mismatch and mechanisms of learning: What the hands reveal about a child's state of mind. *Cognitive Psychology, 25,* 468–523.

Ball, S., & Bogatz, G. A. (1970). *The first year of Sesame Street: An evaluation*. Princeton: Educational Testing Service.

Barab, S. A., Gresalfi, M., & Ingram-Goble, A. (2010). Transformational play: Using games to position person, content, and context. *Educational Researcher, 39*(7), 525–536. doi:10.3102/0013189X10386593.

Baroody, A. J., Lai, M., & Mix, K. S. (2005). The development of young children's early number and operation sense and its implications for early childhood education. In B. Spodek & O. N. Saracho (Eds.), *Handbook of research on the education of young children* (2nd ed., pp. 187–221). Mahwah: Lawrence Erlbaum Associates.

Baroody, A. J., Lai, M.L., & Mix, K. S. (2006). The development of young children's early number and operation sense and its implications for early childhood education. In B. Spodek & O. N. Saracho (Eds.), *Handbook of research on the education of young children* (2nd ed.). Mahwah: Lawrence Erlbaum.

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences, 22*(4), 577–609 (disc. 610–660).

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59,* 617–645.

Barsalou, L. W., Niedenthal, P. M., Barbey, A., & Ruppert, J. (2003). Social embodiment. In B. Ross (Ed.), *The psychology of learning and motivation* (Vol. 43, pp. 43–92). San Diego: Academic.

Bogatz, G. A., & Ball, S. (1971). *The second year of Sesame Street: A continuing evaluation*. Princeton: Educational Testing Service.

Cross, C. T., Woods, T. A., & Schweingruber, H. (Eds.). (2009). *Mathematics learning in early childhood: Paths toward excellence and equity*. Washington, DC: National Academies Press.

Dogan, M. F., Williams, C. C., Walkington, C., & Nathan, M. (2013). *Body-based examples when exploring conjectures: Embodied resources and mathematical proof*. Poster presentation conducted at the Research Precession of the 2013 National Council of Teachers of Mathematics Annual Meeting and Exposition, Denver, CO.

Fisch, S. M., & Truglio, R. T. (2001). *"G" is for growing: Thirty years of research on children and Sesame Street*. Mahwah: Erlbaum.

Fisch, S. M., Lesh, R., Motoki, E., Crespo, S., & Melfi, V. (2011). Children's mathematical reasoning in online games: Can data mining reveal strategic thinking? *Child Development Perspectives,* 5(2), 88–92.

Gee, J. P. (2003). *What video games have to teach us about learning and literacy*. New York: Palgrave MacMillan.

Gelman, R., & Meck, E. (1983). Preschoolers' counting: Principles before skill. *Cognition, 13*(3), 343–359.

Glenberg, A., Jaworski, B., Rischal, M., & Levin, J. (2007a). What brains are for: Action, meaning, and reading comprehension. In D. McNamara (Ed.), *Reading comprehension strategies: Theories, interventions, and technologies* (pp. 221–238). Mahwah: Erlbaum.

Glenberg, A. M., Brown, M., & Levin, J. R. (2007b). Enhancing comprehension in small reading groups using a manipulation strategy. *Contemporary Educational Psychology, 32*, 389–399.

Lauricella, A. R., Gola, A. A. H., & Calvert, S. L. (2011). Toddlers' learning from socially meaningful video characters. *Media Psychology, 14*, 216–232.

Microsoft. (2012). Kinect Sesame Street TV [computer software]. Redmond: Microsoft Studios.

Nathan, M., Kintsch, W., & Young, E. (1992). A theory of algebra-word-problem comprehension and its implications for the design of learning environments. *Cognition and Instruction, 9*(4), 329–389.

National Association for the Education of Young Children [NAEYC]. (2009). *Developmentally appropriate practice in early childhood programs serving children from birth through age 8: Position statement*. Washington, DC: NAEYC. www.naeyc.org/files/naeyc/file/positions/position%20statement%20Web.pdf.

National Association for the Education of Young Children [NAEYC], & Fred Rogers Center for Early Learning and Children's Media. (2012). *Technology and interactive media as tools in early childhood programs serving children from birth through age 8: Joint position statement*. Washington, DC: NAEYC (Latrobe: Fred Rogers Center for Early Learning and Children's Media at Saint Vincent College). www.naeyc.org/files/naeyc/file/positions/PS_technology_WEB2.pdf.

National Council of Teachers of Mathematics (NCTM). (2000). *Principles and standards for school mathematics*. Reston: NCTM.

National Governors Association Center for Best Practices, Council of Chief State School Officers. (2010). *Common core state standards: Mathematics*. Washington, DC: National Governors Association Center for Best Practices, Council of Chief State School Officers. http://www.corestandards.org/the-standar ds/mathematics.

Rothschild, M., Williams, C. C., & Thevenow-Harrison, J. T. (2013a). Counting apples and coconuts: Young children 'Kinect-ing' Sesame Street and mathematics. In C. Williams, A. Ochsner, J. Dietmeier, & C. Steinkuehler (Eds.)*, Proceedings of the 9th Annual Games+Learning+Society Conference* (Vol. 3, pp. 274–280). Pittsburgh: ETC Press.

Rothschild, M., Williams, C. C., & Thevenow-Harrison, J. T. (2013b). Performance assessments. In M. V. Martinez & A. C. Superfine (Eds.), *Proceedings of the 35th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education* (p. 1207). Chicago: University of Illinois at Chicago.

Shapiro, L. (2011). *Embodied cognition*. New York: Routledge.

Squire, K. (2011). *Video games and learning: Teaching and participatory culture in the digital age. Technology, Education–Connections (the TEC Series)*. New York: Teachers College Press.

Steinkuehler, C., & Duncan, S. (2008). Scientific habits of mind in virtual worlds. *Journal of Science Education and Technology, 17*(6), 530–543. doi:10.1007/s10956-008-9120-8.

Walkington, C., Srisurichan, R., Nathan, M., Williams, C., & Alibali, M. (2012). *Using the body to build geometry justifications: The link between action and cognition*. Paper presented at the 2012 American Educational Research Association Annual Meeting and Exhibition, Vancouver, BC.

Walkington, C., Nathan, M., Alibali, M., Pier, L., Boncoddo, R., & Williams, C. (2013). Projection as a mechanism for grounding mathematical justification in embodied action. Paper presented at the 2013 Annual Meeting of the American Educational Research Association, San Francisco, CA.

Meagan Rothschild is an Assessment and Design Specialist at WIDA and a PhD candidate at the University of Wisconsin-Madison. She made the courageous leap to the chilly Midwest from balmy Hawaii to pursue a PhD and work with the Games, Learning, and Society Center. Prior to her move, Meagan served as the Instructional Designer for Cosmos Chaos!, an innovative video game designed to support struggling fourth grade readers developed by Pacific Resources for

Education and Learning (PREL). Her experience at PREL also included the design of a violence and substance abuse prevention curriculum for Native Hawaiian students, using an interdisciplinary approach that merged health and language arts content standards to support literacy-driven prevention activities. Meagan has 6 years of experience in the Hawaii Department of Education system serving in varied roles, including high school classroom teacher, grant writer and manager, technology coordinator, and Magnet E-academy coordinator. Meagan has a BA and MEd from the University of Hawaii at Manoa, with undergraduate studies in Hawaiian Language and special education, and an MEd in Educational Technology. As a PhD candidate in Digital Media and Learning at the University of Wisconsin-Madison, her work now focuses on developing and researching multimedia environments that merge research-based learning principles with interactive/gaming strategies to engage learners. She specifically focuses on the role of play to not only provide opportunities for deeper learning, but to provide relevant contexts for learners to demonstrate content knowledge, challenging traditional views of assessment practices.

Caroline C. Williams is a dissertator at the University of Wisconsin-Madison (specializing particularly in Mathematics Education in the Department of Curriculum and Instruction), and affiliated with the Games+Learning+Society group. Her dissertation involves designing a Little Big Planet 2 game to teach fractions and linear functions, and she specializes in research involving middle school students, mathematics, and all things digital media. Caro has presented and published on a wide variety of topics, including building in Little Big Planet, mathematics in World of Warcraft forum posts, using gestures to support mathematical reasoning, example usage in mathematical proof processes, gender and mathematics, and learning trajectories in linear, quadratic, and exponential functions.

SAPS and Digital Games: Improving Mathematics Transfer and Attitudes in Schools

Richard N. Van Eck

Abstract Many suggest that digital games are a way to address problems with schools, yet research on their ability to promote problem solving, critical thinking, and twenty-first century skill sets appears to be mixed. In this chapter, I suggest that the problem lies not with digital games, but with our conceptualization of what it means to promote problem solving and critical thinking, and how transfer of such skills works in general and, specifically, with games. The power of digital games lies not in some magical power of the medium, but from embedded theories (e.g., situated learning and problem-centered instruction) and from good instructional design (the principles of learning and teaching to which all good instruction must adhere). This chapter describes situated, authentic problem solving (SAPS): a model to explain how digital games can promote transfer and improve attitudes toward mathematics. By examining research on the instructional practices (situated learning) and outcomes (transfer, problem solving, attitudes) that lie at the heart of SAPS, we can chart a path forward for best practices of digital games in mathematics education.

Keywords Situated learning · Authentic assessment · Transfer · Attitude · Attitude toward mathematics · Problem solving · Critical thinking · Engagement · Serious games · COTS games · Integrating COTS games · Games in the classroom

Houston, We Have a Problem

Whether or not our current approaches (hereafter referred to as "traditional") have ever been a successful way to teach is debatable, but it is evident that they are not working today in United States (US) schools. Based on ACT test scores, only 45% of those who graduated from high school in 2011 were prepared for college-level math. US students continue to score below average in mathematics when compared to other Organisation for Economic Co-operation and Development (OECD) countries. In 2012, the US ranked 31st of 65 countries—a fact made

R. N. Van Eck (✉)
Department of Teaching and Learning, College of Education and Human Development, University of North Dakota, Grand Forks, ND, USA
e-mail: richard.vaneck@und.edu

© Springer Science+Business Media Dordrecht 2015

T. Lowrie, R. Jorgensen (Zevenbergen) (eds.), *Digital Games and Mathematics Learning*, Mathematics Education in the Digital Era 4, DOI 10.1007/978-94-017-9517-3_9

even less encouraging when one considers that this is unchanged from 2009 and that 36 countries have been added to the OECD since 2003, when the US actually was ranked sixth from the bottom (OECD 2012).

Traditional approaches not only fail to teach students mathematics, they also fail to engage them. The percentage of US students intending to major in mathematics has been estimated as low as 0.6 %, and US students account for only 10 % of the world's engineering majors (for which mathematics is a key foundational field) (Lutzer 2002). Because of figures like these, most educators agree that we have to focus on *interest* in mathematics in addition to mathematical thinking and computation.

The Problem Starts with Education

While much of the content taught in school remains unchanged from its origins (Thales of Miletus, ~600 BCE, mathematics; Euclid, ~300 BCE, geometry; François Viète's work, ~1600 CE, algebra), the fundamental *ways* we teach that curriculum have changed, and not for the better. Evidence from the early history of mathematics, shows that knowledge was often derived from observation and manipulations of objects in the real world, most often in service of solving real-world problems (e.g., the height of a pyramid and the number of blocks needed to build it), and the ways it was taught reflected that connection to real-world problems. Beginning with the Industrial Revolution in Europe (e.g., Joseph Lancaster's Monitorial System), when mass education became a government- and economics-mandated priority, education has become "boiled down" to the basics and stripped of all meaningful context or relevance. Consequently, methods of teaching mathematics during the last two centuries have been dominated by a computational focus on mathematics in the abstract, with little or no application to the real world.

Things are no better today; we routinely focus on lower-level skills instead of problem solving and do so in highly abstract and decontextualized ways (Woodward and Montague 2000). In one of the most rigorous, large-scale randomized observational studies of classroom practice to date, Pianta et al. (2007) randomly selected 1000 students at birth and followed them through their first 5 years of school, observing them in 2500 classrooms in 1000 schools located in 400 school districts in ten different cities. Among their findings were that the ratio of teaching basic skills versus problem solving was 5:1 for fifth grade and 10:1 for first and third grades. Mathematics problem solving specifically accounted for 7 % of all classroom time, and 91 % of teachers' methodology was either lecture or independent seatwork.

Back to the Future

By removing learning from meaningful, situated contexts, we have actually created less effective learning *and* a whole new problem: failure to transfer. Students today cannot apply the decontextualized learning they get in most classrooms to real-world problems. Most mathematics education experts now believe that the focus should be more on mathematics as a way of thinking rather than a set of discrete skills (Devlin 2011), and our standards bodies seem to agree.

The US Common Core State Standards Initiative (Next Generation Science Standards Lead States 2013) is a state-led effort to develop standards that provide a consistent, high-quality framework across all public schools. Forty-five states in the US have currently adopted the standards, which include mathematics. While these standards focus largely on the expected computational aspects of mathematics education, one of the six identified characteristics of the standards is that they "include rigorous content and application of knowledge through *high-order skills*" (emphasis added). This focus on high-order skills (e.g., problem solving) is further supported by the organizers' emphasis on connecting mathematics to the real world, or what experts call "thinking mathematically" (e.g., Schoenfeld 1992). Consider the following excerpt from the Standards for Mathematical Practice, which are designed to guide the implementation of the standards themselves (emphasis added):

> The first of these are the NCTM process standards of problem solving…. The second are the strands of mathematical proficiency [that include] adaptive reasoning, strategic competence, conceptual understanding …, procedural fluency …, and productive disposition (*habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's own efficacy*)…. Without a flexible base from which to work, they may be less likely to … apply the mathematics to *practical situations*, *use technology mindfully*…. In short [it] prevents a student from engaging in the mathematical *practices*.

The National Council of Teachers of Mathematics (NCTM) has likewise been calling for a renewed emphasis on authentic, real-world problem solving. The 2000 standards make several references to the need for a focus on problem solving and authentic learning (NCTM 2012; emphasis added):

- "Students need to see that mathematics is a human enterprise that, although often abstract, *has tremendous power in explaining and predicting real-world phenomenon*" (p. 29).
- "Active engagement with mathematics is best fostered through … interesting mathematical or *real-world problems*" (p. 35).
- "…[M]odeling and representation are key ideas that must be *anchored in real-world models and phenomenon*" (p. 100).
- "*Real-world contexts* provide many rich and varied opportunities for students to link what they are learning to the world around them and vice versa" (p. 202).
- "Mathematics … should focus on *solving problems* as part of understanding mathematics so that all students … generalize in situations within and outside mathematics … to solve problems and *adapt the strategies to new situations*" (p. 76).

Unfortunately, the standards provide no guidance on how teachers are to achieve these outcomes, and while both allow for, and even advocate, the use of games in mathematics education (e.g., the NCTM lists 25 games on their Illuminations Website), closer examination reveals that most of the games are of the paper-and-pencil variety rather than digital games[1] and focus on computational mathematics at lower

[1] I use the term 'digital games' throughout this chapter to refer to any game that is developed for a digital environment, to include computers, game consoles, handheld gaming platforms, tablet games, etc.

taxonomic levels. Such games provide no answer to our current need to promote problem solving, transfer of learning, and learning to think mathematically.

We lost something critical 250 years ago when we severed the connection to real-world problems in education, or what I refer to as situated, authentic problem solving (SAPS). We lost something that goes far beyond whether people can "do sums"; we lost the ability to think mathematically. With that, we lost generations of potential mathematicians, engineers, and scientists who never saw the connection of mathematics to their lives and the problems they care about solving. Now, our failing schools and standards bodies demand a solution. How will we meet this challenge?

SAPS: A Roadmap Back to the Future Through Digital Games

It may help to describe the SAPS model and framework I will use before beginning this chapter in earnest. SAPS is a model that integrates several instructional theories and approaches, including situated learning, problem solving, transfer, engagement, and attitudes toward learning. Drawing on years of research in each of these areas, the model explains why and how problem solving, transfer, and positive attitudes can be promoted through instruction, including digital game-based learning (DGBL).[2] SAPS explains the apparently mixed results on the use of digital games in promoting these outcomes and points the way toward an effective way of using digital games in mathematics education. I will discuss this research in some detail throughout the chapter as I provide the rationale for this model, but the essential argument is as follows.

Situated learning is an instructional practice whereby learning and demonstration of learning (testing) are situated within an authentic, real-world environment, simulated or otherwise. Asking a student to solve abstract math problems in a workbook is not situated learning; asking a student to figure out how much wood and material will be needed to build a playground for their neighborhood is. Situated learning is an answer to putting learning back into real-world contexts and allows us to promote transfer of learning.

Transfer is the ability to apply what is learned in one context to another context, and it is rarely done by students. Failure to transfer is a largely self-imposed problem resulting from the decontextualized (non-situated) approaches we use in education today. Problem solving is both an instructional outcome (e.g., students are good problem solvers) and a process that learners engage in (e.g., students solve problems as part of their instruction). Problem solving is an important goal that is currently not met by formal education and which can subsume lower-level skills (e.g., computational fluency), making it an efficient instructional goal for mathematics curriculum. When problem solving (as an instructional process) is integrated

[2] I use the term 'digital game-based learning' (DGBL) to refer to the use of games within an existing lesson, classroom, or other instructional context where the intent is at least as much to learn rather than to (exclusively) "have fun".

with situated learning, we get transfer of problem solving and improved attitudes toward instruction.

Digital games are ideal vehicles for these processes and outcomes, and SAPS is a way to guide our practice in evaluating, designing, and using DGBL solutions in mathematics education. Many DGBL advocates today have, in my opinion, mistaken the forest for the trees, in part because they fail to account for instructional design, which is what has led to the fragmented, inconsistent nature of many research findings today (e.g., Hays 2005). In this chapter, I will outline the evidence for digital games as educational tools; describe the relevant research in situated learning, transfer, problem solving, and engagement (attitudes) upon which SAPS is based; relate each to digital games today; and conclude by providing examples and guidance for the application of SAPS to mathematics education.

The Evidence for Digital Games

Digital games are immensely popular with children and adults. According to the Entertainment Software Association (ESA 2013), Americans spent more than $20 billion on digital games and related technology in 2012. Video game play by children has been steadily increasing over the last 15 years, from 26 min in 1999 to 49 min in 2004, and 1 h and 13 min in 2009 (Kaiser Family Foundation 2010). Gaming devices now appear in 42 % of homes, with households with children being nearly twice as likely to own them (Pew 2010).

It is not surprising, then, that DGBL is seen by many as a savior for failing education systems today: digital games are able to teach content, change attitudes, and promote problem solving. There is evidence to support such claims. While success varies with the quality of the instructional design used to develop mathematics games, on average, a well-designed game improves learning over lecture by between 7 % and 40 % and can effectively erase the differences between failing students and those working at a "B" grade level (Mayo 2009). Digital games have been used successfully in a wide variety of domains and areas, including spelling, reading, mathematics, physics, health, biology, computer science, spatial visualization, divided attention, surgical skills, and knowledge mapping (Tobias et al. 2011), as well as combat skills (Kent 1999), language fluency (Baltra 1990; Barrett and Johnson 2010), and transfer of mathematics (Van Eck and Dempsey 2002).

Randel et al. (1992) conducted a review of 68 empirical studies on the use and effectiveness of instructional simulation games, with the vast majority of the games being digital, and found that games are effective in teaching social science, mathematics, language arts, physics, biology, and logic, with mathematics making up the majority of instructional game topics. Fifty-six percent of the studies showed no performance difference between games and conventional instruction, 39 % showed an advantage to games, and 5 % favored conventional instruction. Game use resulted in higher performance in mathematics, physics, and language arts, but less in other areas. Overall, Randel et al. (1992) found an advantage for retention and interest for instructional simulation games over conventional instruction.

Hays (2005) reviewed 105 articles on digital games for learning and concluded that "games can provide effective learning for a variety of learners for several different tasks," including math and attitudes (p. 6). A meta-analysis of 32 studies by Vogel et al. (2006) found "significantly higher cognitive gains … versus traditional teaching methods" for games (p. 233).

So why then do we hear so often that the research on games is, at best, inconclusive? The answer is to be found in our inconsistent application of instructional design. Put another way, games are effective if and only if they adhere to the same instructional design principles as all good instruction. When we think of games as a new means of teaching whose power is inherent in the medium itself rather than a medium that embeds the instructional theories and events we know to be effective, we mistake the medium for the message: "There appears to be consensus among a large number of researchers with regard to the negative, mixed or null findings of games research, suggesting that the cause might be a lack of sound instructional design embedded in the games" (O'Neil et al. 2005, p. 467). Other researchers have come to similar conclusions (e.g., Leemkuil et al. 2003).

Situated Learning

The theory most important to understanding how digital games can improve learning, promote transfer, and increase positive attitudes toward the content is situated learning. Situated learning holds that learning is effective to the degree that it is embedded in a meaningful context (e.g., Brown et al. 1989; Choi 1995; Choi and Hannafin 1995; Lave 1988). Situated learning arises out of a movement in cognitive studies in the 1970s that began to study human cognition in the contexts in which they naturally occur (Cohen and Siegel 1991; Graesser and Magliano 1991; Meacham and Emont 1989). The theory is referred to as situated cognition, while situated learning is the term used to describe instructional methodologies based on situated cognition.

According to situated cognition theory, learning will be most successful if it takes place in authentic environments, using authentic tasks. An authentic environment is one in which the task, process, or concepts are likely to be found in the real world—what Brown et al. (1989) call the "ordinary practices of a culture" (p. 34). Situated learning most often refers to real contexts, but others have extended the concept successfully to simulated, or virtual, contexts. One prominent example is anchored instruction (Cognition and Technology Group at Vanderbilt [CTGV] 1992a, b, 1993). Much of the research on and design of anchored instruction was conducted using videodisc and CD-ROM materials, yet the findings remain relevant to digital games today. In anchored instruction, an environment, context, and story are developed in which the learning events, or "anchors," are embedded. Anchors must represent authentic tasks, processes, and goals. The most well-known example of anchored instruction is the Jasper Woodbury project (CTGV 1992b). This 12-lesson series of adventures was divided into four main mathematical areas: Complex Trip Planning, Statistics and Business Plans, Geometry, and Algebra.

Students learned about the content through watching and interacting with a video story. Researchers often cite anchored instruction as a means of promoting transfer of learning as well (e.g., Anderson et al. 1996; Choi 1995; Choi and Hannafin 1995; CTGV 1993; Vye et al. 1998). Tests of the Jasper Project supported that research (Sherwood and CTGV 1991; CTGV 1993). So situated learning in real or virtual environments has been shown to be effective in learning and transfer of learning. What evidence do we have for the ability of modern digital games to support situated learning?

Situated Learning and Games

Several researchers from different disciplinary perspectives and, in some cases, using different terminology, have posited that digital games are situated learning experiences. Take James Gee's work on video games (e.g., 2007), which relies heavily on the concept of situated learning from a sociolinguistic or semiotic perspective. As a linguist, he is concerned with how we make meaning from words, symbols, images, and artifacts, which he posits "have meanings that are specific to particular semiotic domains and particular situations (contexts). They do not just have general meanings" (p. 24). His argument is, in part, that situations drive meaning and that meaning cannot be derived without context. Learning, from this perspective, is closely tied to the formation of identities through social–cultural–linguistic interactions in what Gee calls "affinity groups." It might be tempting to conclude that this is "merely" about identity formation or language acquisition, but he connects these principles and others to digital games, arguing that games are semiotic domains that require players to make and interpret meaning within a variety of different situations. While his focus is more about process outcomes than about "content" (p. 46), it should be recognized that mathematical thinking and problem solving *are* processes and that transfer of learning will depend on learners being able to "make meaning" of mathematics based on different contexts.

Digital games today, like role-playing games, simulation games, and adventure games, make perhaps the best use of situated learning of all other instructional approaches outside of actual apprenticeship. Digital games situate problems in meaningful contexts where learning and performance are authentic, which decreases the disparity between how learners learn mathematics and how they apply mathematics to real-world problems (i.e., how they transfer learning).

Transfer

Situated learning potentially removes the self-imposed problem of failure to transfer by making learning and performance contexts identical to the real world. Yet there is much to be learned about transfer that can further guide our use of digital games for promoting transfer. Transfer as a learning concept has its origins in the late 1800s in a philosophy called "formal discipline." Formal discipline held that the mind was like a muscle and that learning, like exercise, would improve the overall function of the mind (muscle). Thorndike (1969) and Woodworth (Thorndike and Woodworth 1901) cast doubt on this theory with their proposed theory of identical elements, which stated that transfer was a function of the amount of similarity, or identical elements, between the learning and performance contexts.

Here we see once again the relevance of situated learning, which also emphasizes the similarity between learning and performance contexts. In a game where transfer of mathematics is our goal, then we might design for situated learning by creating a virtual world that resembles the real-world context in which we want our learners to apply the knowledge in the future. So rather than building a game that allows learners to practice solving abstract equations for volume and area over and over until they reach mastery, we might create a game in which the application of volume is essential to achieving a goal that the learner cares about solving (e.g., building a community swimming pool and calculating the water needed to fill the pool with water, or determining how much water it will take to fill enough water balloons to put the neighborhood bully out of commission). In the case of using a commercial game like Zoo Tycoon, we might design problems like calculating the cost of adding a hippopotamus habitat to a zoo, which would involve many mathematical operations, including volume of water needed for the pool, allowing for the displacement of water by “X” hippopotami.

But transfer is more complex than this. Focusing on problem and context similarities ignores the role of the learner herself. The stance learners adopt prior to, during, and after instruction has as much to do with transfer (or failure to transfer) as the problems do. This is why many researchers have argued that social-constructivist theories of transfer are critical to solving the transfer problem. While even this subfield of transfer is too large to convey in the space allotted here, some key tenets will prove useful later in making the connection to transfer via games. In a recent special issue of Educational Psychologist, devoted to the constructivist approaches to transfer, Goldstone and Day (2012) argue that there are three key themes that emerge from this research: the stance, or perspective, of the learner; the role of motivation; and specific instructional strategies that can promote transfer. Intentionality to abstract knowledge to apply to future learning (forward transfer), or to search memory space for prior knowledge that can apply to a current problem (backwards transfer), may be more important than any other consideration. Consider the case where students are unable to solve a problem but, when prompted to consider prior knowledge, are suddenly able to do so. Motivation plays a large role in determining the learner’s stance as well; intrinsically motivated learners may be more likely to adopt more productive stances for transfer during and after learning. And, of course, the prompting, guidance, scaffolding, and strategies used during instruction serve a metacognitive function in helping learners develop and monitor good transfer strategies and to develop into more intrinsically motivated students. It is no surprise that all three are interrelated features.

Perkins and Salomon (2012) suggest a “detect–elect–connect” framework for understanding the multidimensional nature of transfer, in which learners must first detect the opportunity to transfer (similarity of surface or deep structures of two different problems), elect to engage in cognitive effort to connect the two, and connect the two problems by solving the one under study. We have been talking so far only about the last phase as transfer, yet all three are critical and are impacted by different strategies and approaches. They point out that transfer itself is not uniform, with problems that share surface detail and deep structure (same–same) often resulting in positive transfer, while problems that share surface-level characteristics but differ in deep structure (same–different) promote inappropriate transfer, and problems with different surface characteristics but similar deep structures (different–same) often result in blocked transfer. Each situation is different and requires its own approach to teaching, although it could be argued that the most important form is different–same.

An example of same–same might be when a person who knows how to drive a car is able to maneuver a tractor, even though they have never driven one before. The surface features appear similar and the deep structures are the same, so transfer works automatically. Different–same conditions, in contrast, might be when a student has learned how to calculate the duration, fuel cost, and timing of a space launch to Mars using calculus but fails to recognize that the deep structure of the problem is identical to intercepting an asteroid heading to Earth at a point where there is enough fuel and time to destroy it ("We never studied asteroid problems….").

It is this kind of transfer we are most concerned with in traditional mathematics. The two problems just described actually share more surface level detail in common than traditional mathematics. Formulae are traditionally studied in isolation (learning the formulae themselves), then in the abstract (applying the formulae to workbook-style practice problems, e.g., "2 + 2 ="), and finally in a word problem format. It is this latter format that is supposed to encourage and build transfer skills in mathematics, yet research has shown that transfer from word problems to authentic problems does not occur (CTGV 1992b). We teach abstract computational fluency with a few word problems sprinkled in and then are surprised when, without any further guidance, our students cannot apply mathematical thinking to real-world problems. We have to do more to reduce the disparity between school teaching and real-world performance. Early research on transfer has firmly established that transfer is unlikely without learner guidance on the connection between two different contexts or situations (e.g., Adams et al. 1988; Brown 1989; Gick and Holyoak 1980; Hayes and Simon 1977; Lockhart et al. 1987; Perfetto et al. 1983; Reed et al. 1974; Simon and Hayes 1976; Weisberg et al. 1978), yet far transfer (e.g., from abstract, computationally focused mathematics to situated, real-world problems) is more likely to require additional instructional events. This is where digital games can help, once again. By using situated learning, we can teach the mathematics in (simulated) environments that resemble the real-world problems we envision. In other words, digital games allow us to potentially turn far transfer problems into near transfer problems. This is not to say that there is no place for computational fluency training; it remains the best way to truly master the processes. But by first beginning with the situated problems, we establish a meaningful context for computational fluency training.

Transfer and Digital Games

There is a growing body of evidence that learning in digital games can transfer to other contexts. In one of the earliest post-CTGV/anchored instruction studies of transfer and games, Randel et al. (1992) found that junior high students who participated in an instructional game improved in their ability to select prior knowledge and relevant ideas for solving new mathematics problems (transfer).

Gopher et al. (1994) studied Israeli Air Force cadets using a game (Space Fortress II) versus no game, and found evidence for transfer from the game to actual flights. Similar results were found by Hart and Battiste (1992) with one game, but not with another. Also Brown et al. (1997) compared learning from a game about diabetes to another game (unrelated to diabetes or any other medical condition) and found that learning transferred to behavior in terms of better communication with parents and in self-managing diabetes.

I will discuss another game that I developed to promote transfer of mathematics skills later in this chapter as evidence for the efficacy of the SAPS model, and which also promoted transfer of learning. However, one example here may help to illustrate the power of digital games to transfer to the real world in ways that do not involve specific learning content. Re-Mission (Kato et al. 2008) is a game to help pediatric cancer patients learn to monitor and participate in their treatment plans. The game pits you as a nanobot character inside a human body, against cancer cells and antibodies that attack the wrong things, armed with antibiotics and chemotherapy. Research showed that patients who played the game had both a better understanding of their disease and treatment plan and how they interact, and adhered to their medication schedule significantly more than those who did not play the game (Kato et al. 2008). The situated nature of the learning (taking on the role of delivering the chemotherapy to the cancerous cells) changed perceptions of efficacy. It is hard to imagine a case where the stakes for transfer are higher and the clear evidence that a digital game made the difference.

Overall, the research shows that serious games (digital games designed to teach) are successful in facilitating both near transfer and far transfer "sometimes as well as traditional methods, and sometimes better than comparison modes" (Tobias et al. 2011). Again, this should come as no surprise when we consider that well-designed games will adhere to the same instructional principles that all good instruction does, and thus when paired with practices (e.g., situated learning) that have been shown to promote transfer in other venues, they should produce the same things. When we encounter research that indicates a digital game does not transfer, we are most likely looking at a game that does not adhere to situated learning, good instructional design, or which is measuring transfer improperly. So how can we best make use of digital games for the purposes of transfer?

Most researchers believe that improving transfer requires multiple transfer opportunities over an extended period of time (Quinones et al. 1995; Salomon and Perkins 1989). This is another reason digital games can help promote transfer. Unlike good teachers or tutors, digital games are always ready to teach and, when deployed via the Web, can potentially reach millions of people at the same time.

Like good teachers, however, well-designed games embed the instructional events (e.g., guidance, practice, feedback) to support learning and do so without variation no matter how many times they are played and replayed. Digital games allow us, therefore, to provide multiple practice opportunities, with minor variations in context being possible with relatively little effort.

Perhaps the most important aspect of transfer as it relates to digital games is that it is highly context- and domain-specific (e.g., Black and Schell 1995; Bransford et al. 1989, 1986; Brown et al. 1989; Salomon and Perkins 1989; Perkins and Salomon 1989). Experts in one domain do not necessarily perform better in other, related domains. For example, expert chess players do not possess extraordinary memory for chess positions and board sets, but instead rely on the arrangements of the chess pieces as cues for possible moves and strategies. Similarly, Gee argues that all meaning is situated within affinity groups and semiotic domains (like digital games) and that one cannot learn "general" meanings of things; all meaning is mediated by the environment and situation it is embedded within (2007).

It is this finding that best accounts for the disagreement over whether skills learned in digital games can transfer to other domains. If the question is whether playing digital games (and being exposed to the kinds of situated problem solving and critical thinking skills embedded in their particular semiotic domain) will make students better critical thinkers and problem solvers in the real world, the answer is probably "no." The distance between game contexts and real-world contexts, irrespective of specific domains (far transfer), is too great to see any short-term gains. The better question is whether playing those same games will make us better at the kinds of critical thinking and problem solving that go on in other similar games (near transfer), to which the answer is probably "yes." Does that mean that digital games cannot help us with transfer of skills and content taught in formal settings? No. The key is that digital games must situate the skills, problem solving, and critical thinking of our domain of interest (e.g., mathematics) within environments that mirror the application of those skills in the real world. Even then, this will only happen if we have arranged instructional events so that students make the connection between the two different environments. So the answer to the question of digital games and transfer is "yes, *if*" we do not rely on just any digital game to do it all on its own.

Problem Solving

So far, I have been discussing transfer without regard to the taxonomic level of the outcomes, yet problem solving may be the most logical outcome with which to concern ourselves. We do not do it currently (Pianta et al. 2007), yet it is a critical outcome for our schools, subsumes all lower-level skills so is not an "either–or" decision, and is the easiest to connect to real-world scenarios (situated learning). Research on problem solving goes back at least to the 1930s and Gestalt psychology, and a full accounting is neither possible nor warranted here. I will focus here on the key ideas from problem-solving research that impact how digital games and

DGBL can situate authentic problems in meaningful contexts to promote transfer and positive attitudes toward mathematics.

The first key finding for our purposes is that, just as with transfer, problem solving is context and domain dependent. What this means is that problem solving can only be taught within specific domains and not generically by instructional means (e.g., by digital game playing in general). Getting lots of practice solving problems in one domain does not make one a better problem solver in general (e.g., Anderson et al. 1996; Bhaskar and Simon 1977). Just as in Gee's (2007) conceptualization of situated learning, there is no "general" meaning of words, neither are there generalized kinds of problem-solving skills that apply across all domains and problems.

So, when some researchers speak about the ability of digital games to promote 'problem solving,' they are talking about the transfer of a generalized kind of problem solving that does not, in fact, exist. No matter how many digital games one plays, one will not become a better problem solver, per se. One might become better at solving similar problems, which is to say, better at playing games that embody the same kinds of skills and problems one has faced in a game. But when we talk about twenty-first century skills (e.g., Partnership for 21st Century Skills 2009) in the hopes that gameplay will transfer to real-world equivalencies in the future, we are ignoring a wealth of evidence from transfer and problem solving that suggests otherwise.

A second key finding is that because problem solving lies at the top of the intellectual hierarchy (Gagné et al. 2005), it subsumes most of the other intellectual skills in our learning taxonomies.[3] As Devlin (2011) points out in his book, "Mathematics is a way of thinking about problems and issues in the world. Get the thinking right *and the skills come largely for free*" (p. 1). This means that problem solving is the most challenging outcome to design for but also that doing so allows us to simultaneously address the lower-level intellectual skills.

The third key point for our discussion here is that problem solving is both an outcome and an instructional strategy, the former being the result of the latter. As described earlier, promoting problem solving requires providing students with multiple practice opportunities in solving different problems in different contexts. Any instructional strategy, therefore (including digital games and DGBL, as we will see shortly), must be compatible with problems and problem-centered instruction.

The last key point is about the nature of problems themselves. We will rely on this to make the connection to digital games in the next section. It is generally agreed that a problem has an initial state (the set of information and resources present at the beginning) and a goal state (the information and resources that *will* be present when the goal has been met). Jonassen (2002) also characterizes problems as having two components, but with a critical distinction. They have a goal (goal state), which he calls the "unknown" by virtue of the learner not knowing how it will be reached, and *a value* to the learner in achieving that goal. We will see next

[3] That is, rules, concepts, and discriminations; the other varieties of learning (cognitive skills, motor skills, verbal information, and attitudes) are independent of problem solving and other intellectual skills.

that games are themselves problem spaces with initial and goal states, with goals/unknowns and a value to the learner in achieving that goal, and that this makes them good vehicles for promoting problem solving.

Problem Solving and Digital Games

If games are compatible with (or are themselves) problem solving, they should exhibit the same characteristics as problem solving. Games are goal driven, which some might argue makes them problem solving by default. One need only pick up any commercial game and read the marketing material or play the first 5 min of a game to see that this is true. Consider the description for *Game Magazine*'s 2013 Game of the Year Award for Bioshock: Infinite (Irrational Games 2013):

> BioShock® Infinite puts players in the shoes of U.S. Cavalry veteran turned hired gun Booker DeWitt. Indebted to the wrong people and with his life on the line, DeWitt has only one opportunity to wipe his slate clean. He must rescue Elizabeth, a mysterious girl imprisoned since childhood and locked up in the flying city of Columbia…. Together, they learn to harness an expanding arsenal of weapons and abilities as they fight on zeppelins in the clouds, along high-speed Sky-Lines, and down in the streets of Columbia, all while surviving the threats of the air-city and *uncovering its dark secret*.

Like problem solving in other venues, playing a game requires us to formulate a problem space for both the overall goal of the game (e.g., to help Booker rescue Elizabeth and discover the dark secret of Columbia) and the subordinate problems along the way (often numbering in the hundreds for adventure games like this). Everything one does in a digital game is problem solving—there is very little "down" time where actions are either not required (as with cut scenes) or where actions have nothing to do with solving the problem (e.g., customizing the look and feel of your avatar). Also, the player rarely has any of the prerequisite knowledge needed to solve the problem. In Jonassen's problem-solving parlance, this represents the "unknown" (how we will rescue Elizabeth, how to use those weapons and abilities, and what the dark secret of Columbia is). Just as clearly, however, there is a *value* in solving this problem as evidenced by the 3.7 million who had purchased it by May of 2013 (Goldfarb 2013). Providing *valued* problems is what games do that so many other examples of problem-solving instruction fail to do.

The problem (and a game is a complex problem made up of multiple problems) itself guides the learning and serves as the impetus and vehicle for learning all of the subordinate intellectual skills (rules, concepts, and discriminations). For example, consider the following scenario from the game Dark Souls (Namco Bandai 2011):

> I awaken in a dark cell with only a broken sword hilt and vague instructions to fight my way out of the dungeon to ring a bell which will get me out of the world of the undead. I know that I have an inventory with some items in it and, if I have played any game before, know that things I find will be useful in some way during the game (cognitive strategy and a rule). I find a key, some "humanity" (which makes me human until and if I die), and additional swords and armor. When I find a locked door, I realize one of my keys may open it, and there I find some pine resin. Examining it in my inventory tells me that it can increase the potency of my weapons temporarily. Later, after dying several times in a row in my

> attempts to beat the boss monster at the end of the first part of the game, I remember the pine resin, use it on my sword, and combine that with an attack from above which I know from experience does triple damage. I have combined several rules in the game, some of which I knew and some of which I had to learn. These rules have helped me formulate a new complex rule: information can be found that can help guide me as I combine useless things into things that will help me solve problems. This new rule will, in turn, help me later in the game (many times).

Yet we must not lose sight of Goldstone and Day's (2012) trinity of the stance of the learner, the role of motivation, and the specific instructional techniques that can make learners better at transferring mathematical knowledge. In the next section, I will talk about the role of situated learning problem solving and the formation of attitudes, and we will see how a game can address all three. But before we do, it might help to describe one more game; one that we are currently developing. Its goal is to promote expert-like thinking in science measured, in part, by the ability of students to solve analog science problems and to promote positive attitudes in girls regarding engineering science. The working title is Eco Adventure, and it takes place in a city where learners encounter three problems of increasing complexity, each of which forms one of the three levels in this game (L1–L3), in authentic ways (e.g., through the media, conversations, and observation). Using the SAPS model described in this chapter, learners solve these problems under the scaffolded guidance of a mentor. Through their interactions with people in the game, including a diverse group of scientists, local government officials, and community members, learners participate in authentic scientific processes while solving problems that deal with water, soil, and air impacting human, animal, and plant ecosystems. Learners set their own subgoals for play by earning badges, including "Green" badges (by choosing eco-friendly options), "Sleuth" badges (by minimizing the number of visits to key resources), and "Hero" badges (by promoting processes that maximally benefit people and animals). Players travel by clicking locations on the map and selecting the method of transport in order to interview people, conduct research, test solutions, or present findings to the elite Eco-Protector Scientists (EPS) group and to citizens. Our game also employs a variety of scaffolding strategies at key points in the problem-solving process using hints and prompts to get the learner to consider what they may be able to learn (their stance, or intentionality) from the current problem that could be helpful later (forward transfer) or how what they have learned might be applicable to a new problem (backwards transfer). The first problem provides the most scaffolding. Once learners solve this problem they encounter a more complex problem, which requires more from them, and which is accompanied by less scaffolding. The last problem requires learners to solve a more complex problem with multiple solutions, none of which is perfect. They receive almost no support along the way for this problem. Automatic, proximal measures such as deviation from the optimal solution path, elapsed time between key problem nodes, and patterns of responses to EPS questions are used to approximate measures of the learner's current thinking and to trigger mentor intervention in science.

So there is evidence that digital games are a kind of problem-solving instruction themselves and therefore should be just as effective as other instructional modalities in supporting problem-solving instruction. As situated learning environments (e.g., we play a specific character in a setting driven by a consistent narrative), digital games should also promote transfer. In the next section, I will talk about how these all work together to also promote positive attitudes toward instructional content.

Situated Learning, Problem Solving, and Attitudes

While we must increase mathematical ability, including at the computational level (where most of the test scores focus), increasing competence is no guarantee of increasing *interest* in the field of mathematics and related disciplines. While we might expect that increasing mathematics skills would result in some people feeling more positive about the field, attitude is formulated only in part by competence and self-efficacy. It is also important to show students that mathematics solves problems they care about, like building bridges, planning a playground, or calculating fund-raising needs to provide meals for the homeless for a year.

Low motivation and low self-confidence in math (Middleton and Spanias 1999) contribute to students' low levels of effort and poor learning outcomes. Research has shown that students who struggle with math are more engaged when math instruction is situated in real-life scenarios (Bottge et al. 2007). By combining situated learning and problem solving, we show students that mathematics solves real-world problems they *value*, which can help them come to see the value of mathematics itself (improved attitude).

We often talk about motivation, engagement, and fun in the same breath, but they are in fact very different phenomena. In my opinion, games (and all good learning) *ARE* about engagement if we recognize that engagement is *less* about fun and *more* about an effortful process that results from full employment of the learner's cognitive faculties (e.g., during problem solving). Recall Jonassen's concept of problems requiring both a goal, or unknown, and a *value* to the learner in meeting that goal. Digital games are "engaging" not because they are "fun" but because there is a *value* in the problems they ask the player to solve. Engagement results in part from problem solving, which is why DGBL should focus on both situated learning and problem solving. Figure 1 shows where I believe engagement is generated during problem solving.

In this model, it is actually failure, not success, that generates engagement. If the primary motivation for playing digital games (or engaging in any other effortful task) was the "fun" of being successful alone, most games would not be fun. As with digital games, most of our time in problem solving is spent in failure and remediation. Failure leads to cognitive disequilibrium, a state Piaget argued that is critical for our ability to "accommodate" new knowledge by restructuring our mental models or schemas. Higher-order learning is more likely to require accommodation, whereas lower-level learning is more likely to require assimilation (the process of "fitting" similar information into existing schemas without modification). When a learner makes a prediction and finds she is wrong, she wants to resolve this disequilibrium quickly and to begin asking questions like, "Why was that wrong? What did I miss?" This, in turn, prompts her to revise her hypotheses, take a new action to test them out, etc. Good *problems* will keep learners in this cycle, while good *instruction* (the events surrounding problem solving in formal learning

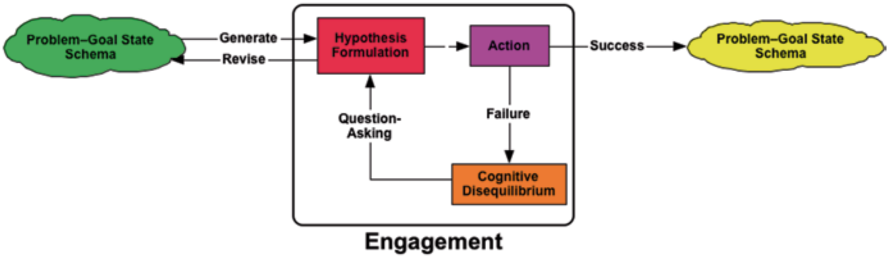


Fig. 1 Engagement as a function of the problem solving process

environments) will provide scaffolding and support so learners are operating at their maximum cognitive capacities, or what Vygotsky (1978) called being in the Zone of Proximal Development.

It is not too much of a stretch to see how the game I described earlier (Eco Adventure) combines both problem solving and promotes positive attitudes. The problems in conservation and ecology rarely seem like "typical" science problems to students, who are used to solving decontextualized problems that bear little resemblance to the things they care about. When the reason a student is solving a problem is to save wildlife, protect habitat, or provide safe drinking water for children, the process (and therefore the content) becomes more relevant. Students are in turn more motivated to solve them and may develop more positive attitudes toward the content areas. Remember that motivation is one of the three key themes in promoting transfer (Goldstone and Day 2012); the motivation from solving these problems in a game may be enough to get over the "elect" hump to which Perkins and Salomon (2012) refer.

So in addition to designing our curriculum around real world, authentic problems that our students find relevant, we have to recognize that our goal is not to make learning "fun" or to find ways for our students to *easily* achieve success. Rather, our goal is to find ways to *engage* them—to make them work at their maximum cognitive capacity and to design problems that make them fail regularly but about which they care enough to want to work through that failure with our guidance and support (scaffolding). Digital games are an ideal vehicle for this, which is why they can be an important part of mathematics education.

SAPS Model, Mathematics, and Games

Putting what we know about situated learning, problem solving, transfer, and engagement together yields the SAPS model for designing DGBL that should, based on prior research, promote transfer and problem solving and improve attitudes toward the content. There are examples and research that show it can be effective. Van Eck and Dempsey (2002) undertook a study to see if a digital game that made use of this model could promote far transfer of mathematics formulae to real-world problems and to improve attitude toward mathematics. In the game, the student plays the niece or nephew of a couple who fixes up houses. The player has been hired to help work on a house and has been assigned the tasks of calculating the amount of paint needed to paint a room and the amount of wallpaper border needed to paper the perimeter. The game is an immersive 2D environment with video avatars of the aunt and uncle, who can be summoned to ask questions as needed. The avatars appear in the doorway of the room when called, and are "embedded" (situated) in the environment as if they had just come in from the other room. No learning or demonstration of learning happens outside of the game or narrative context of the story.

Students who are taught to solve problems of area and perimeter in traditional, decontextualized ways typically fail to transfer those skills to contextually embedded problems. Thus, "calculating how much paint to use" to paint a room seems to many to be something they never learned (far transfer). Providing hints and scaffolding (through the avatar/advisement) helps them see that walls are squares or rectangles, that the vaulted ceiling comprises triangles and rectangles, and that the doors, windows, etc., are also shapes for which the area can be calculated and added/subtracted as needed. The advisement is the explicit instruction regarding the similarity of school mathematics contexts to real-world (in this case, simulated) contexts.

One-hundred-and-twelve middle school children were randomly assigned to one of five conditions formed by crossing "advisement" (contextualized video advisors or text-based advisors) and competition (competing against a character or not). Participants in the control group were given a computer-based tutorial containing word problems that were numerically and semantically identical to those in the program. Transfer of mathematics skills was assessed via a second computer-based instructional simulation identical to the simulation game in the treatment conditions in terms of structure and general content but differing in the setting (a theater instead of a house; near transfer). Transfer was measured solely by the ability to solve the problem.

Participants in the contextualized advisement condition without competition had higher transfer scores (0.82) than participants in the no contextualized advisement without competition (0.25). Participants in the no contextualized advisement with competition condition had higher transfer of mathematics scores (0.78) than those in the contextualized advisement with competition (0.47). It seems that those in the contextualized advisement conditions did best when competition was not present, while those in the competition conditions did best when no contextualized advisement was present.

It may be that the presence of competition creates an affective environment in which contextualized advisement cannot be fully attended to or processed because learners are concerned about the time they have taken (which is displayed on screen) and with beating the competitor. In other words, competition may inhibit metacognitive skills, attention, and elaboration. Further research with this game also showed that the SAPS model can improve attitudes toward the content, even after only 50 min of gameplay (Van Eck 2006). Players who participated in the conditions where the advisors were contextually embedded video avatars (situated advisement) within the game environment showed less anxiety toward mathematics at the end of the game than did those who received help in the form of text (abstract, or non-situated advisement). Results were particularly significant for those who were in the competitive conditions.

While one study does not prove a theory, this is not the only example of evidence for this approach. Research on the use of SAPS approaches has continued to provide evidence that higher-order learning and transfer can be promoted through games. For example, transfer from games to real-world skills has been seen in medical fields (e.g., Dobnik 2004), aviation (e.g., Gopher et al. 1994; Hart and Battiste 1992) and a variety of visual, cognitive, and psychomotor skills (Tobias et al. 2011).

David Williamson Shaffer has proposed a theoretical approach for conceptualizing game-based curriculum that holds great promise for promoting transfer and which reflects current thinking on transfer as a complex, socially situated process. Focusing on content as a way of thinking, he argues for "Pedagogical Praxis," (Shaffer 2004a) in which we design instruction based on the culture (situated learning) of the professions in which our domains are used in the real world. Students are thus encouraged to speak like experts, use the same tools as experts would use, and in other ways behave as experts in the given domain. Shaffer has extended his theory to the use of games ("epistemic games"). He has tested these epistemic games in a variety of domains and with different learners, and has found they can promote higher-order thinking and the development of expertise (Shaffer 1997, 2002a, b, 2004b), including mathematics. Among the key elements in his research with geometry, for example, was that the software was "autoexpressive," meaning that the tool's behavior reflected the student's conceptual understanding of the domain (e.g., mathematics).

The concept of autoexpressivity is perhaps of most significance for our purposes because it is the result of the alignment between the actions in the microworld (simulation game) and the domain of interest. The tool behaves according to underlying rules of the domain, and such, it is a direct reflection of the learner's current conceptual understanding of the domain. The environment and the domain are perfectly aligned, which then provides continuous and consistent feedback to the learner about her own (in this case, mathematical) understanding.

Chris Dede has also done important work that reflects the SAPS approach. One of his most significant efforts in this area is River City (Clarke 2007; Clarke et al. 2007; Ketelhut 2007; Ketelhut et al. 2007; Nelson et al. 2006), which is an example of what he calls a Multi-User Virtual Environment (MUVE). River City is designed explicitly around situated learning principles and has produced results consistent with prior research on situated learning and performance, motivation, and transfer outcomes. This virtual world focuses on a city (River City) where the population is becoming ill. It is unclear what the cause of the illness is, and it is up to the student to solve this problem. The players are "sent back in time" (River City is a nineteenth-century era US town) to explore the town, interact with residents, collect data, conduct experiments, and answer questions in a lab notebook. Through exploring the environment, interacting with the inhabitants, and sharing their results, they discover that economically disadvantaged families are disproportionately affected, and that there are several factors involved, including polluted water runoff to low-lying areas, insect vectors in swampy areas, overcrowding, and the cost of access to medical care. At the end, students write to the mayor of River City describing the health and environmental problems they have encountered and suggesting ways to improve the life of the inhabitants.

River City has been implemented with more than 1000 students in different middle schools and resulted in performance benefits (higher test scores than comparison groups), motivational improvement (attitude toward content, attitude toward domain, and self-efficacy), engagement in school (lower absence rates, reduced disruptive behavior), and perhaps most importantly, evidence for better inquiry (problem solving) and transfer. Students report, and their in-game actions and learning artifacts reflect, feeling more like a "real" scientist, understanding the connection between what they are learning (the domain) and how it aligns with the real world (Ketelhut 2007; Ketelhut et al. 2007).

Barrett and Johnson (2010) describe an approach consistent with SAPS within the context of sociocultural learning theory, which combines elements of Gee's, Shaffer's, and Dede's approaches. They have developed games for learning language (Farsi) in cultural contexts. Rather than learning phrases in isolated, abstract training environments, learners enter a game world in which they learn the language by trying to get around in an Arabic country. They land at the airport, and must interact with customs officials, taxi drivers, hotel staff, etc. In learning the language, they also learn cultural (situated) knowledge about idioms, what to ask first, topics to avoid, etc. Failure results in the behavior that would occur if the player were in-country (e.g., the taxi driver takes you to the wrong place, or is offended by the manner in which you asked to be transported and leaves you at the airport). These games, which rely on artificial intelligence to generate actual conversation, have been tested with more than 50,000 people and found to be effective in learning language, but more importantly, they appear to result in real-world transfer. In studies of the trainees in the field, it was found that the 3rd Battalion of the 7th Marine Regiment did not suffer a single casualty because, in the opinion of the commanders, the training was so effective in learning the language.

One can see in all of these examples both similarities and extensions of the ideas discussed earlier by other researchers. Gee's affinity groups and semiotic domains are echoed in Shaffer's epistemic frames, which extend these ideas to include ways of thinking and behaving within specific professions and domains.

Implications for Mathematics Education

Given our need to improve computational mathematics and problem solving, our desire to promote transfer, and the abilities of games (through situated learning and problem solving) to do all this while also improving attitudes, we would seem to have a blueprint for the future. What does a focus on SAPS approaches to learning mean for those on the front lines of education? In the remainder of this chapter, I will attempt to provide specific advice about putting this all into practice, covering some additional concepts along the way to help complete the picture.

Promoting Transfer and Problem-Solving Skills with Digital Games

Before we talk about specific ways to use digital games for mathematics education, it is important to remember that what makes for good DGBL in this regard is what makes for *any* good instruction—adherence to core instructional design principles. Unfortunately, good instruction is hard to develop. Worse, problem-solving curriculum and transfer are the hardest instructional outcomes to develop for. Add to this that DGBL is the most difficult medium to develop for, and you have a recipe for some of the hardest instruction you can design. We should be sure, therefore, that we are seeking DGBL for the right reasons and that we have the time and resources to implement it. For example, the home improvement game I described earlier that was successful took approximately 1000 h to develop and implement. SAPS is an approach that can be developed with or without digital games in mind, however, so just because a SAPS digital game *can* be used to teach lower-level skills does not mean the effort is always justified.

And when we do find digital games are compatible with the SAPS approach, we have to remember Jonassen's second maxim for problem solving; that the problem should have some *value* to the learner. Too often, we ignore this component, relying instead on our ability to convince students to "trust" us; that it will be useful "someday." Finding problems that our *students* care about (rather than problems *we* think are valued) can be harder than it sounds. Digital games must therefore reflect the kinds of problems our students value, not that we value or think our students *should* value. The best way to find those problems is to involve students in the process—make them co-designers. Students love nothing more than being asked for their opinion.

Finally, the contexts in which we situate those relevant problems must be relevant and transferable to our final domain environments. It can be possible to find a good problem that is valued by students but which does not map well enough to the content. The time it takes to implement good DGBL will only pay off if we address enough of the content under study. So the problems we identify should require enough of the sub-skills we have taught or wish to teach so our students learn to solve problems as well as gain fluency with the computational sub-skills those problems require.

Using Designed Games

The most effective way to use digital games in the classroom is to design the games from the ground up to teach what we want. That way, we can ensure the best content coverage and the most effective application of the SAPS model. Whether designing or selecting serious games for the classroom, there are several things to look for.

First, make sure the game is explicitly aligned with curriculum standards that your school values (e.g., the Common Core). Games in the classroom can be a tough sell to administrators, parents, and even students, so the conversation has to begin and end with achieving instructional goals you cannot otherwise meet easily. Those standards should then be mapped to specific content areas in your curriculum.

Once you know the game meets your goals (and that you can articulate how and why when asked!), evaluate the game yourself as a player. Contact the developer to get access to the game and to any professional development materials they may have, and play the game. Look for things like how well the content (the problems) is integrated (situated) within the game itself and how authentic the problems are. Shaffer's idea of autoexpressivity is key here: does the game require demonstration of the skills and concepts in order to advance, or does it use gameplay to "reward" traditional instruction? The game should be centered around problems that would normally require the application of those skills to solve. Mathematics is itself embedded in a variety of real-world activities rather than being a profession, per se (mathematicians and educators notwithstanding!), so the problems in the game and the processes used to solve them should be situated and authentic.

McLarin's Adventures (K20 Center 2008) is a game in which players use mathematics to help survey a planet they have landed on. While this context is clearly fantasy-based, the process of surveying land (problem solving) is quite realistic (regardless of what the flora and fauna of that world look like!) and, most importantly, the use of mathematics and related surveying, graphing, and mapping tools is highly authentic. Application of mathematics skills is directly relevant to advancement in the game, and the game and tools are autoexpressive in that the students' conceptualization of the mathematics is reflected in the tools and game behavior. The game is aligned with the Common Core mathematics standards and has been used with thousands of students in dozens of schools around the country and has been found to be effective in promoting learning.

Project Selene (CyGaMEs 2007) is a game in which players learn about how moons form by "building" their own moon. They must choose how much matter to accrete over what period of time, while monitoring the geological processes that govern moons versus asteroids versus debris. The context is much more realistic than McLarin's Adventures, in that you are simply in space working with debris. Of course, this technology is not actually possible now, so the setting is still fantastic, but the game and its relation to the domain of interest is still authentic. The game is aligned with the National Science Education Standards, the American Association for the Advancement of Science Atlas of Science Literacy Strand Maps, and the Next Generation Framework for K-12 Science Education. It has won several prestigious awards and has been shown to be highly successful in promoting transfer of scientific knowledge in public school curriculum.

Contemporary Studies of the Zombie Apocalypse (Triad Interactive Media 2013) is a game that is geared toward middle school students and is an adventure game that uses the SAPS model in which players routinely encounter real-world aspects of abstract mathematical concepts (Fig. 2). In addition to problem solving, players learn to think about the world mathematically, with abstract concepts manifested within the game world in visual, relevant ways. Humanity finds itself living underground because of a zombie infestation. Once a year, four children win the lottery

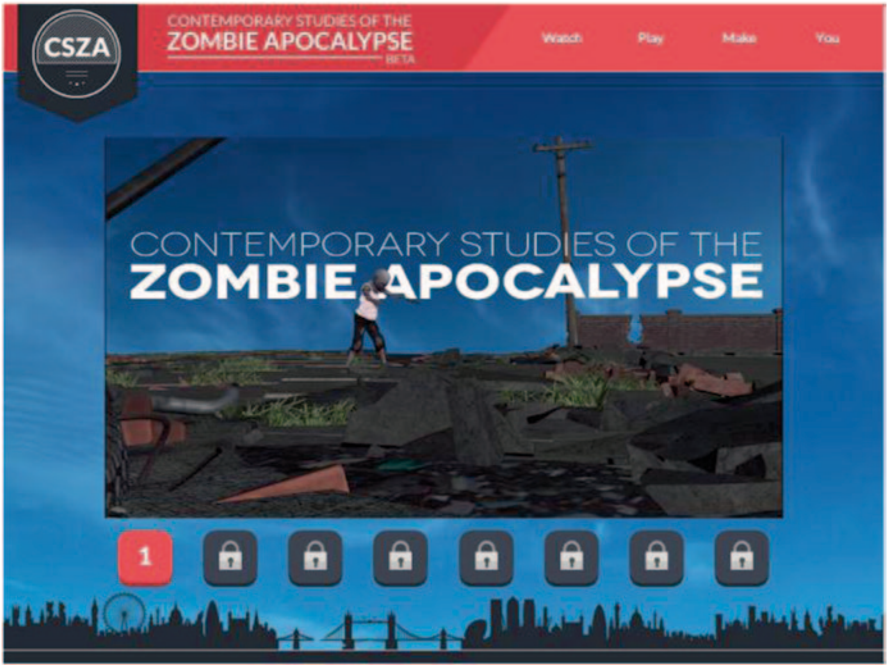


Fig. 2 Home Screen of CSZA

and are allowed up to the surface to scout things out. All is not as the corporate government state would have them believe, however, and through a series of adventures (which require mathematical problem solving, all situated within the context of the narrative), the children come to realize the surface is not all that bad (despite the odd zombie) and decide to live up there. In addition to problem solving and a series of fluency/computational skills learned along the way, this game also has a unique feature in which concepts like convex, concave, linear, and periodic are manifested in visually relevant ways. For example, players choose between "continuous" and "discontinuous" holographic images of themselves to help them fool the zombies as they walk through the street. The discontinuous image jumps around and appears and disappears randomly, while the continuous image is projected a set distance away and mimics the player's actions. These concepts are normally presented in abstract ways, making it difficult for students to transfer to real-world examples later. This aspect of situated learning allows players to develop conceptual understanding of abstract principles as things they can connect to the real world, which in turn provides context for the abstract problems they also must be able to solve. The key to ensuring this transfer (both from abstract to concrete, and then back again to abstract) lies in debriefing and making that connection explicit. In other words, it is not enough to watch students complete the problems; we have to also talk to them about *how* and *why* they were able to solve those problems.

Integrating Commercial Games

Another way to use digital games for mathematics education is to use existing commercial games. Commercial, off-the-shelf (COTS) digital games are far more prevalent than serious games and have the advantage of being valued problems by virtue of the marketplace. So what about the use of COTS games that have not been designed for these purposes as part of our DGBL? Can they also promote problem solving and transfer? The answer is that they can, if we understand how they are both similar and different than these other approaches and if we embed them in larger lessons that make use of good instructional design (DGBL).

As you might expect, using COTS DGBL involves the same theoretical and practical approaches we have already discussed, but the ways in which situated learning and authentic problems are manifested in COTS games differ from the first approach. With COTS games, you do not have as much control over the content of the game itself and instead must work around the limitations of the game. But this is not the no-man's land it might first appear to be.

Just as you must analyze serious games for their autoexpressivity, the value of their problems to your learners, and the content coverage you require, with COTS games you will also need to identify where there are gaps and inaccuracies in the game content or where the strategies employed by the game for solving the challenges is insufficient (e.g., trial-and-error vs. reasoned thinking). In other cases, the game may lead to misconceptions or an incomplete picture of the content and skills. And since you cannot change the game itself (in most cases), these are the places where you will need to design extension activities to extend the learning. And because the commercial game is not explicitly about the content itself, you must also develop instruction that helps learners see the connection to the content under study.

But while this sounds like more work than a serious game would require (and in some ways, it is), it is not so different from any DGBL. No game perfectly replaces an entire unit of instruction. Just as with any other medium, integrating any game into your curriculum will involve the design of a curriculum within which to embed the game as one modality. This might be more familiar if we switch the medium—nobody expects that showing a movie (e.g., *Old Yeller*, or *To Kill a Mockingbird*) will serve as a stand-alone unit of instruction—we design pre-instructional activities, homework, application exercises, worksheets, classroom activities, and assessment methods. And these are then deployed according to a plan, with the instructor serving as coach, facilitator, guide, assessor, etc. The same is true for digital games and DGBL.

Your goal in specifying these activities to address the strengths and weaknesses in a given COTS game is not to provide "the answers," but to support learners as they generate the knowledge necessary. As you do so, you should think in terms of designing problems, roles, and projects that are *authentic* to the game environment and which serve your learning outcomes as described earlier. So while it is possible to generate a problem that addresses the gaps in the learning outcomes supported by a given game, we must (1) tie the problem to the problems in the game, (2) tie the roles of the learners to the roles in the game AND to the people who would be involved in solving such problems, and (3) tie those roles to the kind of project that such people would work on in order to solve those problems. In short, we have to ensure that the principles of authenticity and situated learning permeate the full scope of our instructional solution (our DGBL).

So how do you identify a good COTS game? Titles are your first clue about whether a game might be applicable to your curriculum. Game titles like Civilization, 1701 A.D., and Zoo Tycoon all convey enough information about their content to make them candidates for further evaluation to teach history or biology, for example.

But the relevance of a game to your content is not always apparent from the title. Understanding what the game actually *requires* of the learners and how autoexpressive the game mechanics are in terms of authentic (not realistic) content opens up a whole range of COTS games for DGBL that might at first glance appear to be of little value. While it seems obvious that Zoo Tycoon might have application for biology, playing the game and analyzing it reveals that some of the other primary content areas for this game are economics, business, marketing, and mathematics. Zoo Tycoon requires that one manage the business of the park, attending to outputs from a fairly sophisticated simulation of the zoo's financial health. Factors like costs, customer satisfaction, and animal health are influenced by (and require adjustments from the player to) the number of animals, cost of their appropriate habitats and food, the number of food stands, money spent on maintenance and sanitation, and the prices of admission and services. Roller Coaster Tycoon (Atari 2003) is another COTS game that, in addition to the business and mathematics applications of Zoo Tycoon (Microsoft Studios 2001) can be related easily as well to mathematics (calculus) and physics. Roller coasters, in the real world, are built by engineers who must know physics and mathematics. While the game itself does not *require* this knowledge, it is reasonable (and authentic!) to expect that building roller coasters in the game world would normally be done by engineers using these skills, and thus be subjected to the same constraints as in the real world (e.g., safety inspections, design document and blueprints, computer simulations). It is reasonable to posit that engineers built the roller coasters, even if the game does not employ them. Thus, the activities we design around the game can leverage authentic problems while remaining situated within the game fantasy and still address our content areas and outcomes.

Further, the same game can be used to teach these areas at different grade levels by varying the complexity of the supporting activities. Middle school and high school students might write simple reports and design documents about one part of a specific roller coaster using Newton's laws and basic computations of energy, mass, and acceleration as project outcomes, while undergraduate and graduate students could generate detailed design specifications and reports that focus on higher-level calculus, vectors, conceptual physics, and stress tolerances for an entire roller coaster, or even build simulations to test existing designs. Middle schoolers might write reports (as zoo managers) about the financial health of the zoo or (as exhibit designers) proposals about a new animal acquisition and habitat, while graduate business majors write detailed analyses of the underlying economic model of the zoo simulation and predict its behavior if it were based on a different economic model. By focusing on the strategies required during gameplay (the autoexpressivity) rather than just the surface content of the game, one finds that there are many games out there with potential to teach a wide variety of topics at several grade levels. This is a complex process presented in more detail elsewhere (Van Eck 2008).

Having Students Build Games

The third and final way to use games to teach mathematics is to put the design process in the hands of students. In this approach, students use a variety of tools to build their own games. A variety of tools exist for this purpose (e.g., Scratch, GameMaker, RPG Maker), many of which are inexpensive or free. Whereas in the past building games was only appropriate for teaching computer programming, with the addition of instructional design elements, one can use this strategy to teach any content. For our purposes, mathematics, the key lies in finding elements of the game design that embody mathematical concepts (the game design itself is problem solving).

When creating virtual worlds, one has to define the space (area) and decide how many things can be in that space (density) and how far apart they are in relation to their size (scale). When populating that space with people, one has to consider travel time (speed × distance), how much weight can be carried, how much damage each person can do in combat, etc. When populating the world with artifacts such as weapons and loot that can be acquired, one must determine how much each costs and how much it weighs, so that when a character attempts to carry it, he or she will only carry items for which there is room, and when he or she attempts to sell it, we know how much it is worth. We have to determine how much protection each type of clothing and armor should provide versus how much its mass will slow the user down. All of these things require the generation of algorithms (e.g., weight of items slows down travel speed; selling items leads to transfer of money from one place to another; weapon damage vs. armor class × strength of attacker).

Because all such real-world projects (building a game) require planning, it is a normal (authentic) practice to generate these specifications ahead of time and test them on paper (mathematically) before taking time to develop them. It is true that many game tools will generate a lot of these decisions for the player, and it is possible to populate that world *without* a plan. As teachers, though, we can (and must) place constraints on the experience so that it is embedded in a full lesson plan rather than allowing the game activity to stand on its own. Remember that transfer cannot occur without additional instruction to support it as an outcome. We create the requirements to plan and work authentically with the mathematics in the context of game design so that students see the relevance and so we can ensure all the instructional events are present to ensure learning. This includes specific instruction on the connection between the mathematics and the environment/activity.

In addition to game design tools, there are some games that allow players to design new levels or maps to extend play within the game. These tools are invariably free and can be a great resource for this kind of DGBL. One example is the game Portal (Valve 2007). In this game, you control a robot that has to find a way through a series of challenge rooms by following marked paths blocked in various ways by the testing facility the player finds him or herself in to start the game. To solve for the unknown, the player must solve puzzles by manipulating levers, springs, acceleration technology, and portals that warp dimensional space to avoid things that will harm the player's character. For example, to get across one room, I may have to push a cube onto a button that triggers a door to get into a room that will let me use my portal gun to open a pathway to another part of the room that has a spring-loaded launcher that will fling me over an acid bath obstacle but only if I shoot a portal in the wall while in mid-air so I come out in a different room. Obstacles and devices can be combined in thousands of ways to make an infinite number of challenges, and Valve has released Puzzle Maker software that allows players to make their own test chambers using these tools. Note that in addition to the mathematical elements described previously, this game offers additional options relating the mass of cubes and the player character (a robot) versus the force needed to trigger a switch and the stored kinetic energy of spring launchers, all calculated against gravitational forces and navigation of 3D space. Planning such puzzles would, authentically, involve making mathematical calculations as part of the design document, thus providing a context for mathematics study.

Final Thoughts

It might seem from this chapter that the issue of transfer and games is both well-researched and settled. The truth is that most of what we think we know about games and transfer is based on thought experiments that extend prior empirical research. There is no question that more empirical research must be done, both on games and transfer, and on how they do and do not work together. We have little reason to believe, however, that situated learning principles, which have received significant support in past modalities, would suddenly become less effective when used to design games, for example. To be sure, each new medium influences the message; we may know something about the instructional strategies (scaffolding) needed to help promote transfer and still not know the best way to deliver them in different kinds of gaming environments. But the tools exist and the theories are sound, so the only thing stopping us from answering these questions is the will to do the research that is needed.

And in that regard, this chapter serves as much as a guide for the work that must yet be done as a definitive treatise on how games promote transfer. The procedures and examples I have presented here are about how DGBL and COTS DGBL can be designed to promote problem solving and transfer while meeting our curriculum goals. There is, of course, a lot more involved in putting it into practice. And it is important to remember too that digital games are by no means the only way to achieve these goals. In fact, the only reason games are effective in this regard is that they employ theories that have stood the test of time, decades before the arrival of the digital game. Digital games are, however, a very good model for how to build situated, authentic problem-solving environments, which we know is a goal that eludes most educators. So I leave you here with some parting thoughts to keep in mind as you seek to integrate digital games into mathematics instruction.

Remember That It Is About the Theory, Not the Medium

Transfer is promoted through repeated exposure to a wide variety of problems in different contexts. The more similar the learning and performance contexts are, the more likely transfer will occur, although there is no guarantee. The more problems we are exposed to, and the more varied the contexts of those problems, the more likely we are to exhibit far transfer. Authenticity is more important than realism—ensuring that the problem requires the authentic application of the skills under study will trump whether that problem is "realistic" or not. Engagement is about cognitive effort and autonomy, not about fun. It emerges from effortful learning that we pursue for the value of solving the problem.

Remember That Not All Instruction Must Be Realistic, Authentic, Situated, or Problem Based

Lots of instructional goals can be achieved without going to this much trouble! Do not fall into the trap of trying to use digital games for all learners, all content, all the time. A jet will get you to the grocery store, but a bike or pair of tennis shoes will do so too, and you won't have the problem of parking! If you can achieve your goals without developing authentic, situated, problem-centered learning, then do so. Use problem solving, situated learning, and DGBL when and where they are needed.

Remember to Use the Right Game for the Right Purposes

Space does not allow for a discussion of the different types of problems that exist any more than it does for the different kinds of games. Logic problems (e.g., the classic dinner party logic puzzle) differ from moral dilemmas, for example, and games like *Jeopardy* (verbal information) (Friedman 2013) differ from games like Bioshock (problem solving). My colleague and I have made some preliminary efforts to address these differences and to align different problem and game types. Figure 3 presents a summary of these findings, for which the full context can be found in the chapter referenced there.

	Knowledge and Cognitive Process													
	Domain–specific knowledge[1]				*Higher–order thinking*						*Psychomotor skills*[2]		*Attitude change*[2]	
Problem type	Declarative	Procedural	Concepts	Principles	Logical	Analytic	Analogical	Strategic	Systemic	Metacognitive	Muscular movement	Muscular–cognitive coordination	Shift of belief system	**Game type**
Logical					+	+								Adventure; Puzzle
Algorithmic		+	+	+	+									Adventure; Puzzle; Action
Story	+	+	+	+	+	+	+							Adventure; Puzzle
Rule-use	+	~	~	+	+	+								Action; Strategy; Roleplaying; Adventure; Puzzle
Decision–making		~	+	+	+	+		+	~	~				Action; Strategy; Role-playing; Simulations; Adventure
Troubleshooting		+	+	~	+	+	+	+	~	~				Simulations
Diagnosis–solution		+	+	+	+	+	+	+	+	+				Simulations; Strategy
Strategic Performance		+	+	+	+	+	+	+	+	+	+	+		Action; Roleplaying; Simulations; Adventure
Case Analysis			+	+	~	+	+		~	+			~	Strategy
Design			+	+	+	+	+	+	+	+				Strategy
Dilemma				+	+	+	~	+	+	+			+	Strategy; Roleplaying

Fig. 3 Problem types, their associated cognitive processes, and learned capability outcome, and the gameplay types that might best support them. For the problem types that are more complex and highly contextualized, the acquisition of domain knowledge is assumed to be required, and for purposes of readability, is not marked in this figure (Reprinted with permission from Hung and Van Eck 2010). (Note: [1]For the learning type under Domain Knowledge, application of the knowledge is also assumed in this chart. [2]For Psychomotor Skills and Attitude Change: domain-specific procedural and principle knowledge and metacognitive thinking are assumed. + signifies "always required."; ~ signifies "sometimes required.")

Games Are a Part of, Not a Replacement for, the Curriculum

Games are no shortcut to instructional design—rather, they require more than other forms of instruction in many ways. They also allow us to achieve higher goals than we can otherwise achieve, which makes them worthwhile. So we need to choose where we use them carefully. To justify the significant effort they take to plan and implement, we should use them for problems that can cover significant portions of our curriculum and for which we do not have good instructional solutions.

The stakes for mathematics education have perhaps never been higher, with the growing STEM gap and continued evidence that US students lag behind their international peers. Fortunately, we know what to do, and digital games can be a great way to do it—but only if our practice is based on theory and if we don't fall prey to the hype about games being fun, automatic, or easy ways to do it.

References

Adams, L. T., Kasserman, J. E., Yearwood, A. A., Perfetto, G. A., Bransford, J. D., & Franks, J. J. (1988). Memory access: The effects of fact-oriented versus problem-oriented acquisition. *Memory and Cognition, 16*(2), 167–175.

Anderson, J. R., Reder, L. M., & Simon, H. A. (1996). Applications and misapplications of cognitive psychology to mathematics education [1]. Unpublished paper. http://act.psy.cmu.edu/ACT/papers/misapplied-abs-ja.html. Accessed 17 July 2013.

Atari. (2003). *Roller Coaster Tycoon* [PC game]. USA: Atari.

Baltra, A. (1990). Language learning through computer adventure games. *Simulation and Gaming, 21*(4), 445–452.

Barrett, K. A., & Johnson, W. L. (2010). Developing Serious Games for Learning Language-in-Culture. In R. Van Eck (Ed.), *Gaming and cognition: Theories and perspectives from the learning sciences* (pp. 282–315). Hershey: IGI Global.

Bhaskar, R., & Simon, H. A. (1977). Problem solving in semantically rich domains: An example from engineering thermodynamics. *Cognitive Science, 1,* 193–215.

Black, R. S., & Schell, J. W. (1995, December). Learning within a situated cognition framework: Implications for adult learning. Paper presented at the annual meeting of the American Vocational Association, Denver, CO. (ERIC Document Reproduction Service No. ED 389 939).

Bottge, B. A., Rueda, E., Serlin, R. C., Hung, Y.-H., & Kwon, J. M. (2007). Shrinking achievement differences with anchored math problems: Challenges and possibilities. *Journal of Special Education, 41*(1), 31–49.

Bransford, J., Sherwood, R., Vye, N., & Rieser, J. (1986). Teaching thinking and problem solving. *American Psychologist, 41*(10), 1078–1089.

Bransford, J. D., Franks, J. J., Vye, N. J., & Sherwood, R. D. (1989). New approaches to instruction: Because wisdom can't be told. In S. Vosniadou & A. Ortany (Eds.), *Similarity and analogical reasoning* (pp. 470–497). New York: Cambridge University Press.

Brown, A. L. (1989). Analogical learning and transfer: What develops? In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 369–413). Cambridge: Cambridge University Press.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18,* 32–42.

Brown, J. S., Lieberman, D. A., Gemeny, B. A., Fan, Y. C., Wilson, D. M., & Pasta, D. J. (1997). Educational video game for juvenile diabetes: Results of a controlled trial. *Medical Informatics, 22*(1), 77–89.

Choi, J. I. (1995). The effects of contextualization and complexity of situation on mathematics problem-solving and attitudes. (Doctoral dissertation, Florida State University, 1995). *Dissertation Abstracts International, 56*(10), 3884 A. (UMI Microform No. 9605031).

Choi, J. I., & Hannafin, M. (1995). Situated cognition and learning environments: Roles, structures, and implications for design. *Educational Technology Research and Development, 43*(2), 53–69.

Clarke, J. (2007). *Trajectories of participation: A pilot study of students' behaviors in a multiuser, virtual environment*. Poster presented at the 2007 American Educational Research Association Conference, Chicago, IL.

Clarke, J., Ketelhut, D., Nelson, B., Erlandson, B., Dieterle, E., & Dede, C. (2007). *Investigating students' behaviors, patterns, and learning in a multi-user virtual environment designed around inquiry*. Paper presented at the 2007 American Educational Research Association Conference, Chicago, IL.

Cognition and Technology Group at Vanderbilt [CTGV]. (1992a). An anchored instruction approach to cognitive skill acquisition and intelligent tutoring. In J. W. Regian & V. J. Shute (Eds.), *Cognitive approaches to automated instruction* (pp. 135–170). Hillsdale: Lawrence Erlbaum Associates.

Cognition and Technology Group at Vanderbilt [CTGV]. (1992b). The Jasper experiment: An exploration of issues in learning and instructional design. *Educational Technology Research and Development, 40*(1), 65–80.

Cognition and Technology Group at Vanderbilt [CTGV]. (1993). Anchored instruction and situated cognition revisited. *Educational Technology, 33*(3), 52–70.

Cohen, R., & Siegel, A. W. (1991). A context for context: Toward an analysis of context and development. In R. Cohen & A. W. Siegel (Eds.), *Context and development* (pp. 3–23). Hillsdale: Lawrence Erlbaum Associates.

CyGaMEs. (2007). *Project Selene* [Video game]. CyGaMEs, Wheeling Jesuit University.

Devlin, K. (2011). *Mathematics education for a new era: Video games as a medium for learning*. Natick: A K Peters.

Dobnik, V. (2004, April 7). Video game playing surgeons make fewer mistakes. *Associated Press.*

Entertainment Software Association [ESA]. (2013). Essential facts about the computer and video game industry. http://www.theesa.com/facts/pdfs/ESA_EF_2013.pdf. Accessed 17 July 2013.

Friedman, H. (Producer). (2013). *Jeopardy* [Television series]. Hollywood: Sony Pictures.

Gagné, R. M., Wager, W. W., Golas, K. C., & Keller, J. M. (2005). *Principles of instructional design* (5th ed.). Belmont: Wadsworth/Thomson Learning.

Gee, J. P. (2007). *What video games have to teacher us about learning and literacy*. New York: Palgrave/Macmillan.

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology, 12,* 306–355.

Goldfarb, A. (2013). *BioShock Infinite has shipped 3.7 million copies*. San Francisco: IGN. http://www.ign.com/articles/2013/05/13/bioshock-infinite-has-shipped-37-million-copies. Accessed 14 July 2013.

Goldstone, R. L., & Day, S. B. (2012). New conceptualizations of transfer of learning. *Special Issue of Educational Psychologist, 47*(3), 149–258.

Gopher, D., Weil, M., & Bareket, T. (1994). Transfer of skill from a computer game trainer to night. *Human Factors, 36,* 387–405.

Graesser, A. C., & Magliano, J. P. (1991). Context and cognition. In R. Cohen & A. W. Siegel (Eds.), *Context and development* (pp. 57–76). Hillsdale: Lawrence Erlbaum Associates.

Hart, S. G., & Battiste, Y. (1992). Flight test of a video game trainer. In *Proceedings of the Human Factors Society 36th Annual Meeting* (pp. 1291–1295). Santa Monica: Human Factors and Ergonomics Society.

Hayes, J. R., & Simon, H. A. (1977). Psychological differences among problem isomorphs. In N. J. Castellan, Jr., D. B. Pisoni, & G. R. Potts (Eds.), *Cognitive theory* (Vol. 2, pp. 21–41). Hillsdale: Lawrence Erlbaum Associates.

Hays, R. T. (2005). The effectiveness of instructional games: A literature review and discussion. Technical Report 2005-004. Naval Air Warfare Center Training Systems Division. http://oai.dtic.mil/oai/oai?verb=getRecordmetadataPrefix=html&identifier=ADA441935. Accessed 4 Nov 2014.

Hung, W., & Van Eck, R. (2010). Aligning problem solving and gameplay: A model for future research and design. In R. Van Eck (Ed.), *Interdisciplinary models and tools for serious games: Emerging concepts and future directions* (pp. 227–263). Hershey: IGI Global. doi:10.4018/978-1-61520-719-0ch010.

Irrational Games. (2013). *Bioshock: Infinite*. [Console game]. Boston: Irrational Games.

Jonassen, D. H. (2002). Integration of problem solving into instructional design. In R. A. Reiser & J. V. Dempsey (Eds.), *Trends and issues in instructional design & technology* (pp. 107–120). Upper Saddle River: Merrill Prentice Hall.

K20 Center. (2008). *McLarin's Adventures* [Video game]. Norman: K20 Center.

Kaiser Family Foundation. (2010). *Generation M^2: Media in the lives of 8- to 18-year-olds*. Menlo Park: Kaiser Family Foundation.

Kato, P. M., Cole, S. W., Bradlyn, A. S., & Pollock, B. H. (2008). A video game improves behavioral outcomes in adolescents and young adults with cancer: A randomized trial. *Pediatrics, 122,* 305–317.

Kent, S. L. (1999, June 23). For military, games hone combat skills. *USA Today*, p. 2D.

Ketelhut, D. J. (2007). The impact of student self-efficacy on scientific inquiry skills: An exploratory investigation in River City, a multi-user virtual environment. *The Journal of Science Education and Technology, 16*(1), 99–111. http://www.springerlink.com/content/p006mh0776u28384. Accessed 14 Nov 2012.

Ketelhut, D. J., Dede, C., Clarke, J., Nelson, B., & Bowman, C. (2007). Studying situated learning in a multi-user virtual environment. In E. Baker, J. Dickieson, W. Wulfeck, & H. O'Neil (Eds.), *Assessment of problem solving using simulations*. Mahwah: Lawrence Erlbaum Associates.

Lave, J. (1988). *Cognition in practice: Mind, mathematics, and culture in everyday life*. New York: Cambridge University Press.

Leemkuil, H., de Jong, T., de Hoog, R., & Christoph, N. (2003). KM Quest: A collaborative Internet-based simulation game. *Simulation & Gaming, 34,* 89–111.

Lockhart, R. S., Lamon, M., & Gick, M. L. (1987). Contextual transfer in simple insight problems. *Memory and Cognition, 16*(1), 36–44.

Lutzer, D. J. (2002). Mathematics Majors 2002. Notices of the American Mathematical Society (AMS).

Mayo, M. J. (2009). Video games: A route to large-scale STEM education? *Science, 323*(5910), 72–89.

Meacham, J. A., & Emont, N. C. (1989). The interpersonal basis of everyday problem solving. In J. D. Sinott (Ed.), *Everyday problem solving: Theory and application* (pp. 7–23). New York: Praeger.

Microsoft Studios. (2001). *Zoo Tycoon* [PC game]. USA: Microsoft.

Middleton, J. A., & Spanias, P. A. (1999). Motivation for Achievement in Mathematics: Findings, Generalizations, and Criticisms of the Research. *Journal for Research in Mathematics Education, 30*(1), 65–88.

Namco Bandai. (2011). *Dark Souls* [Console game]. San Jose: Namco Bandai.

National Council of Teachers of Mathematics [NCTM]. (2012). Mission [Web page]. Reston: NCTM. http://www.nctm.org/mission.aspx. Accessed 16 July 2013.

Nelson, B., Ketelhut, D. J., Clarke, J., Dieterle, E., Dede, C., & Erlandson, B. (2006). Robust design strategies for scaling educational innovations: The River City MUVE case study. In B. E. Shelton & D. A. Wiley (Eds.), *The educational design and use of computer simulation games*. Rotterdam: Sense Press.

Next Generation Science Standards [NGSS] Lead States. (2013). Next Generation Science Standards: For states, by states. Achieve, Inc., on behalf of the twenty-six states and partners that collaborated on the NGSS. http://www.nextgenscience.org/next-generation-science-standards. Accessed 5 Feb 2014.

O'Neil, H. F., Wainess, R., & Baker, E. (2005). Classification of learning outcomes: Evidence from the computer games literature. *The Curriculum Journal, 16*(4), 455–474.

Organisation for Economic Co-operation and Development [OECD]. (2012). Education at a glance indicators. http://www.oecd.org/edu/eag2012.htm. Accessed 10 July 2013.

Partnership for 21st Century Skills. (2009). P21 Framework Definitions. http://www.p21.org/storage/documents/P21_Framework_Definitions.pdf. Accessed 23 Nov 2013.

Perfetto, G. A., Bransford, J. D., & Franks, J. J. (1983). Constraints on access in a problem solving context. *Memory and Cognition, 11*(1), 24–31.

Perkins, D. N., & Salomon, G. (1989). Are cognitive skills context-bound? *Educational Researcher, 18*(1), 16–25.

Perkins, D. N., & Salomon, G. (2012). Knowledge to go: A motivational and dispositional view of transfer. *Educational Psychologist, 47*(3), 248–258.

Pew Internet and American Life Project [Pew]. (2010). *Americans and their gadgets*. Washington DC: Pew Internet and American Life Project. http://www.pewinternet.org/~/media//Files/Reports/2010/PIP-Americans%20and%20their%20Gadgets.pdf. Accessed 7 Feb 2014.

Pianta, R. C., Belsky, J., Houts, R., Morrison, F., & The NICHD Early Child Care Research Network. (2007). Opportunities to learn in America's elementary classrooms. *Science, 315,* 1795–1796.

Quinones, M. A., Sego, D. J., Ford, J. K., & Smith, E. M. (1995). The effects of individual and transfer environment characteristics on the opportunity to perform trained tasks. *Training Research Journal, 1*(1), 29–49.
Randel, J. M., Morris, B. A., Wetzel, C. D., & Whitehill, B. V. (1992). The effectiveness of games for educational purposes: A review of recent research. *Simulation and Gaming, 23*(3), 261–276.
Reed, S. K., Ernst, G. W., & Banerji, R. (1974). The role of analogy in transfer between similar problem states. *Cognitive Psychology, 6,* 436–450.
Salomon, G., & Perkins, D. N. (1989). Rocky roads to transfer: Rethinking mechanisms of a neglected phenomenon. *Educational Psychologist, 24*(2), 113–142.
Schoenfeld, A. H. (1992). Learning to think mathematically: Problem solving, metacognition, and sense-making in mathematics. In D. Grouws (Ed.), *Handbook for research on mathematics teaching and learning* (pp. 334–370). New York: MacMillan.
Shaffer, D. W. (1997). Learning mathematics through design: The anatomy of Escher's World. *Journal of Mathematical Behavior, 16*(2), 95–112.
Shaffer, D. W. (2002a). The design studio: A promising model for learning to collaborate: Thoughts in response to Hall, Star, and Nemirovsky. In T. Koschmann, R. Hall, & N. Miyake (Eds.), *Computer support for collaborative learning 2* (pp. 223–228). Mahwah: Lawrence Erlbaum Associates.
Shaffer, D. W. (2002b). Design, collaboration, and computation: The design studio as a model for computer-supported collaboration in mathematics. In T. Koschmann, R. Hall, & N. Miyake (Eds.), *Computer support for collaborative learning 2* (pp. 197–222). Mahwah: Lawrence Erlbaum Associates.
Shaffer, D. W. (2004a, July). Pedagogical praxis: The professions as models for postindustrial education. *Teachers College Record Volume, 106*(7), 1401–1421.
Shaffer, D. W. (2004b). When computer-supported collaboration means computer-supported competition: Professional mediation as a model for collaborative learning. *Journal of Interactive Learning Research, 15*(2), 101–115. Norfolk: AACE.
Sherwood, R. D., & Cognition and Technology Group at Vanderbilt [CTGV]. (1991, April). *The development and preliminary evaluation of anchored instruction environments for developing mathematical and scientific thinking*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake Geneva, WI.
Simon, H. A., & Hayes, J. R. (1976). The understanding process: Problem isomorphs. *Cognitive Psychology, 8*(2), 165–190.
Thorndike, E. L. (1969). *Individual differences and their causes* (Vol. 2 of *Educational psychology*, and originally published in 1903 as *Educational Psychology*). New York: Arno Press and the New York Times: American education series.
Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions: I, II, and III. *Psychological Review, 8*(3, 4, 6), 247–261, 384–395, 553–564.
Tobias, S., Fletcher, J. D., Dai D. Y., & Wind, A. P. (2011). Review of research on computer games. In S. Tobias & J. D. Fletcher (Eds.), *Computer games and instruction* (pp. 127–221). Charlotte: IAP.
Triad Interactive Media. (2013). *Contemporary Studies of the Zombie Apocalypse* (videogame). USA: Triad Interactive Media.
Valve. (2007). *Portal* [PC game]. USA: Valve.
Van Eck, R. (2006). The effect of contextual pedagogical advisement and competition on middle-school students' attitude toward mathematics and mathematics instruction using a computer-based simulation game. *Journal of Computers in Mathematics and Science Teaching, 25*(2), 165–195.
Van Eck, R. (2008). COTS in the classroom: A teacher's guide to integrating commercial off-the-shelf (COTS) games. In R. Ferdig (Ed.), *Handbook of research on effective electronic gaming in education* (pp. 179–199). Hershey: Idea Group.
Van Eck, R., & Dempsey, J. (2002). The effect of competition and contextualized advisement on the transfer of mathematics skills in a computer-based instructional simulation game. *Educational Technology Research and Development, 50*(3), 23–41.

Vogel, J. F., Vogel, D. S., Cannon-Bowers, J., Bowers, C. A., Muse, K., & Wright, M. (2006). Computer gaming and interactive simulations for learning: A Meta-analysis. *Journal of Educational Computing Research, 34,* 229–243.
Vye, N. J., Schwartz, D. L., Bransford, J. D., Barron, B. J., Zech, L., & the Cognition and Technology Group at Vanderbilt. (1998). SMART environments that support monitoring, reflection, and revision. *Metacognition in educational theory and practice* (pp. 305–346). Mahwah: Larence Erlbaum Associates.
Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Cambridge: Harvard University.
Weisberg, R., DiCamillo, M., & Phillips, D. (1978). Transferring old associations to new situations: A nonautomatic process. *Journal of Verbal Learning and Verbal Behavior, 17,* 219–228.
Woodward, J., & Montague, M. (2000, April). *Meeting the challenge of mathematics reform for students with learning disabilities*. Paper presented at the Annual Convention for the Council for Exceptional Children, Vancouver, Canada. http://www2.ups.edu/faculty/woodward/Enhancing%20-%20LDQ.pdf. Accessed 17 July 2013.

Richard N. Van Eck is Associate Dean for Teaching and Learning and the founding Dr. David and Lola Rognlie Monson Endowed Professor in Medical Education at the University of North Dakota (UND) School of Medicine and Health Sciences at the University of North Dakota, in the United States of America. He has also served for 11 years as a professor of Instructional Design and Technology at UND and for 5 years at the University of Memphis, Tennessee, where he was also a member of the Institute for Intelligent Systems. He has been studying games and learning since 1995 when he entered the PhD program at the University of South Alabama and worked as an instructional designer or developer on several learning games there, including Adventures in Problem Solving (Texas Interactive Media Award 1999) and Ribbit's Big Splash (Gulf Guardian Award 2002; Environment Education Association of Alabama's 2002 Best Environmental Education Award). Since then he has been a researcher and designer on several other STEM games, including PlatinuMath (mathematics game for pre-service teacher education), Project NEO (science game for pre-service teachers), Project Blackfeather (programming game for middle school students), Contemporary Studies of the Zombie Apocalypse (mathematics game for middle school students) and Far Plane (leadership game for high school students and adults). Dr. Van Eck is a frequent keynote speaker nationally and internationally on the educational potential of videogames, and his scholarship on games, in this area includes dozens of books, chapters and refereed publications, and more than 75 presentations on games and learning including talks at TEDx Manitoba and South By Southwest. In addition to his work on serious games, Richard has also published and presented on intelligent tutoring systems, pedagogical agents, authoring tools, and gender and technology.

Mathematics and Educational Psychology: Construction of Learning Environments

Cesare Fregola

Abstract When primary school children learn mathematics, highly complex phenomena occur. These phenomena have been studied in various disciplinary contexts and are organized in a complex and interdisciplinary synthesis, of which references can be found within the evolution of neurosciences, and the psychology of learning as well as experimental psychology. These disciplines are all valuable resources to refer to when researching and experimenting ways to create, plan and realize mathematics learning environments. Particularly for mathematics, these environments aim to facilitate the process of abstraction, stimulate the capacities and abilities that are necessary when entering the realm of mathematics, understand its characteristics, develop and make it possible to develop the skills required to be able to master its language and its uses, and, above all, the motivation to learn. Video games, if conveniently used, can represent learning environments. This essay proposes some reflections that are the result of research and experimentation based on the prerequisites described here. The central focus is mathematics, its prerogatives, and *thought and action in teaching* when it is integrated with the exploration of simulation games and video games, which are an integral part of a digital native's daily life. Just as mathematics is embedded in real-life, art, and science, so are the laws of learning hidden in actions, thought and emotions. With careful observation of children playing video games, it was possible to discover a combination of abilities and skills which are made explicit and are described in this essay.

Keywords Learning environments · Simulation games · Dimensions of mathematics learning · Gagné's hierarchy of learning

---

C. Fregola (✉)
Faculty of Primary Education, L'Aquila University, L'Aquila, Italy
e-mail: cesare.fregola@uniroma3.it

© Springer Science+Business Media Dordrecht 2015
T. Lowrie, R. Jorgensen (Zevenbergen) (eds.), *Digital Games and Mathematics Learning,*
Mathematics Education in the Digital Era 4, DOI 10.1007/978-94-017-9517-3_10

A Communication Learning Environment for Mathematics and Mathematics Teaching

The ubiquity of mathematics in nature, art, science, and music, is often found in many publications. Galileo's passage on the *Language of The Book of Nature*, which appears in one of his works, is one of the most significant observations that reveals the connection and link between mathematical language and what it expresses and is capable of expressing:

> The essence of the world (…) is written in this grand book (and I mean the universe), which stands continually open to our gaze, but it cannot be understood unless one first learns to comprehend the language in which it is written. It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures, without which it is humanly impossible to understand a single word of it; without these, one is wandering about in a dark labyrinth.

However, despite the fact that mathematics is such an intrinsic part of reality, it is not always easy to recognize it at first sight, or to be aware of it every time it appears. In order to be able to see mathematics and master the salient aspects that characterize it as a language capable of expressing concepts, patterns, structures, and both simple and complex phenomena, it is necessary to have keys at one's disposal with which one can open the doors to its world. According to Devlin (2007, p. 195), mathematics manifests in at least two ways, a natural one and an abstract one.

It can be hypothesized that *natural mathematics* lays the foundations for *instinctive, unconscious knowledge*, recognizable to those who are able to describe it in as much as they have studied it, have worked out its patterns, discovered some of its functions and formalized them within the context of a mathematical framework. Tim Pennings, mathematics professor at Hope College, Michigan[1], while observing his pedigree dog retrieve a ball thrown into the water from the beach, was able to notice that the strategies used by the dog followed a process that connected the running speed on the beach with the swimming speed. In fact, the stretch of beach that the dog covers before entering the water is the result of a complex elaboration, a characteristic of infinitesimal calculus when it is used to achieve something in *minimum time*! Thus it is discovered that the dog does not run in a straight line, and this is also true for basketball players who run after the ball as it drops, following a path that is unconsciously driven by an elaboration process which has been studied and formalized in *abstract mathematics*, and added to its theoretical foundations. It can be claimed that there is a type of mathematical knowledge that is used unconsciously and intuitively in a number of different situations, in all kinds of social and work contexts and in the interpretation of natural phenomena, as well as in organizational, technological and artisan processes. The examples arguing the case such as *instinctive, unconscious mathematical knowledge*, also involve humans. The key to understanding this *knowledge* requires a grasp of the language, of that very knowledge, that mathematicians have created a code for, within the context of their discipline.

[1] Compared to Devlin (2005), p. 13.

When instinctive mathematics is used and applied intentionally, a specific language is required, with patterns and schemes that characterize and give form and structure to the second type indicated by Devlin, namely, *abstract mathematics*. This is the type of mathematics that mathematicians deal with.

At this point things get complicated, because the essence of mathematics as part of human culture and its scientific evolution have made it possible to answer the question: "What is mathematics?" (Courant and Robbins 1972; Kline 1985; Maracchia 1975), in different epochs, starting with conceptions and convictions, as well as the results obtained from research on its foundations with the answers changing several times over the course of history (Devlin 2003).

It is appropriate to remember that in Gödel's 1930 work, he redefines the expectation of finding certainty at the base of mathematics (Lolli 2002). The various hypotheses of being able to lay the foundations of the discipline by finding a rigorous, formal justification, along with the definitions and deductions on which it is based, are refuted.

> This is the story today (…). The teaching programmes or publications that reduce it to a form of logical reasoning are unilateral and wrong. But neither is it possible to present mathematics as a science that reveals the secret and simple structures of nature, such as the language of natural laws, since we now know that the relationship between mathematics and nature is much more indirect and complicated, and that nature is not as simple as was once believed. On the other hand, if mathematic representation cannot always simplify the complexity of nature, in what way is it useful? One might as well describe facts using ordinary language. This accumulation of problems makes it even more difficult to answer the question about the nature of mathematical objects. (…) However, over the centuries mathematics has come a long way, and it could not be more different from how it was in Euclid's day…. (Isdrael and Millán Gasca 2012, p. 22)

A dear friend of mine, who directed scientific documentaries, suggested making a distinction between the knowledge required to build a film camera (which involves the expert engineers who design it, the technicians and finally, the different types of factory workers), from the knowledge required to make film documentaries. I have often thought that the level of knowledge concerning a 'film camera' is an asset, but I remain in doubt as to how much basic and useful know-how is required to manage this knowledge, and the actual skills required to make successful documentaries in terms of quality, effectiveness and efficiency.

Leaving metaphors aside, mathematicians increasingly agree on the differences between mathematics, its epistemology and its application, while their views differ greatly in the matter of the teaching methods and educational psychology skills that may characterize the process of teaching and learning mathematics. Obviously, it is necessary to take into account the type of school being addressed; but *teaching* mathematics today, across the board, means guiding students through a discovery of the world of numbers, forms and space. This is needed in order to shape logical reasoning, stimulate critical thinking and arouse elements of awareness, guided by processes that give direction and structure to the mind so as to stimulate the skills of analysis, synthesis, coding, decoding and transcoding, which the study of mathematics requires. If, on the one hand, the process of abstraction, generalization and transfer underlie the construction of mathematical language (Resnick and Ford 1981), it is precisely this construction that requires the activation of metacognitive and socio-relational processes (Fregola 2010a) that, in turn, can lead to the capacity for problem solving, and making decisions in uncertain situations, which are the hallmarks of the social complexity of these times.

These elements form the basis for self-efficacy (Bandura 2000) and can contribute to autonomy from self-limiting schemes that were automatically learned in childhood when a set of convictions is formed about oneself, others, and the world (Berne, Montuschi, and Fregola). As is well known, *self-efficacy* is the ability to carry out adequate and appropriate actions for specific purposes and enables a person to anticipate how to behave in order to reach set goals. Self-efficacy is based on the personal conviction of knowing how to use one's abilities efficiently, by putting oneself in the condition to act in a transformative way (Olmetti Peja 2007, p. 46). *Autonomy* implies a fundamental passage, namely, that of being, and being able to perceive oneself, as an active agent capable of making choices and decisions, elaborating strategies that form the basis of behaviour that facilitates the possibility of relating with the outside world, from an evolving perspective which focuses on the person's relationship to his/her own learning…of mathematics (Fregola 2011).

In this respect, the words of Emma Castelnuovo (1964), the academic who was a forerunner in Italian mathematics teaching, are still valid today. She wrote:

> Philosophical doctrines, pedagogic research, psychological investigation and social issues have led to statements concerning fundamental principles on general teaching doctrines that cannot be ignored if one is to take a serious approach to teaching

and she continues the preface to her book by specifying that if, on the one hand, a maths lesson is:

> (…) usually boring … the young people who come out of our secondary schools today very often have the idea that mathematics, on the one hand, consists of pure mechanical processes, and on the other hand, is a perfect construction that is, at this point, complete, so they wonder whether there are still discoveries to be made in this discipline.[2] (p. 1)

Thus, when researching the answer, "what mathematics is", and taking into account Devlin's views, there are at least three different directions that can be taken in educational research.

1. the rediscovery of natural mathematics;
2. the reconstruction of mathematical language and the definition of the minimum levels of formal mathematics knowledge; and
3. the reconnection between these two worlds so that another type of knowledge can arise, which leads to developing awareness and understanding of the mathematics that is hidden in nature, technology, human behaviour and mastering mathematical skills that are abstract or generalized and organized in a formal structure which enables it to be used in a variety of contexts and for studying, for people for whom it has central importance in their working lives and in research.

[2] Little more than half a century has passed since then, and the fact that these affirmations can still be applied to present-day students, leads one to wonder about the effectiveness of educational psychology research on the mathematics teaching-learning process.

These points can be shared with mathematicians and professional communities who, out of necessity or choice, must have access to, and occupy partly or completely, this mathematical 'space'.

This paragraph aimed to highlight the fact that the educational matter for the learning of mathematics is still an opened theme that became more and more complex. Some relevant considerations on this subject open a question on which the subsequent paragraph will be articulated.

Can a Place Exist for a Systemic Mathematical Teaching Approach?

Educational research and educational psychology (Perini 1997) have developed considerably (Camaioni and Di Blasio 2007), and as a consequence, teaching has found fertile terrain for creating its own theoretical foundations. "Maths teaching should both refer to and encapsulate the entire body of research *on disseminating mathematical… knowledge,* combining at the same time the art of teaching and the scientific studies on this art" (Brousseau 2008, pp. 40–48). According to Bruno D'Amore (1999), mathematics teaching cannot be reduced to a simple application of disciplines such as psychology, sociology, pedagogy, linguistics or history, even if it must have a connection with these (Heritage 2007; Heritage et al. 2009). One of the reasons of this inefficacy in the integration between the various disciplinary sectors is because teaching mathematics requires a solid mathematical background which allows for the necessary reflection on the theories studied. In fact, when we talk about teaching mathematics we talk about improving the quality of teaching, but the mathematical contents are still at the heart of the matter as well as the teaching techniques, along with the ploys used by experienced teachers that, through trial-and-error, become established practices and confirm the idea that teaching mathematics is an art, even though it has given rise to interesting results (D'Amore 1999, p. 31).[3]

There is another element to be taken into consideration. Thanks to developments in neuroscience, it is possible to assume that there is a certain similarity between *natural mathematics* and the world of *learning*. In fact, as far as we know, the laws of learning are often set in motion regardless of the level of knowledge. Slowly but surely, models are used that allow one to understand some processes thanks to which knowledge, memory, attention, motivation and emotions can be developed. But there are still few experimental indications on how this meta-knowledge may be used to organize, facilitate or direct learning in general, and in particular, learning mathematics.

To paraphrase Rivoltella (2012), one may say that an interesting contribution to the development of mathematics instruction can be found in the relationship

[3] Bruno D'Amore (1999) proposes an analysis of possible interpretations of mathematics teaching by moving in the direction of a theory of teaching mathematics itself.

between neuroscience and knowledge technologies which, nevertheless, must be connected with themes and motives and with teaching activity.[4] An example of this can be found in studies on numerical intelligence (Lucangeli et al. 2007), thanks to which it is possible to detect learning paths which integrate the results of research on cognitive and neuropsychological patterns with traditional teaching methods (Lucangeli et al. 2011).[5]

It is useful to our argument to remember that, in 1905, the psychologist Binet proposed an intelligence model with a procedure which was based on a comparison between the mental age and the actual age. In 1912, the psychologist Stern perfected this method by introducing the concept of intelligence quotient (IQ) as the relationship between the mental age and actual age, multiplied by 100. The American psychologist Howard Gardner (1989, 1995, 1999) distinguishes nine types of intelligence and, among these, proposes a logical-mathematical intelligence, which he defines as the human mind's capacity to resolve any problem by following the principles and rules of Logic. It is characterized above all by the ability to discover, invent and reason, and proves to be particularly useful in many human activities, both intellectual and pragmatic (Olmetti Peja 2007). This completes the possibility of understanding a person's internal aspects, which would allow those who work in the field of mathematical instruction to draw on knowledge that could contribute significantly to the devising, planning and management of mathematical learning environments. This would take into account not only the interpretive models that come from mathematics, but also models that can provide indications about what could be defined as instinctive meta-knowledge that stems from the workings of our mind and gradually reveals itself.

The hypothesis that motivates our work is that it is possible to place the relationship between the student and his/her own learning at the heart of the teaching-learning process, in so far as *the encounter with knowledge activates processes that border on intention and surprise* (Fregola 2011, p. 104).

Philosophical doctrines cannot ignore the needs and characteristics of digital natives (Prensky 2001) and the evolution of virtual epistemology (Lévy 2005), that introduces the need for further research (see Fregola 2010a) into how natural mathematics and the world of abstract mathematics are both separate and connected.[6]

[4] Compared to previous paragraph.

[5] Interesting applications of this research can be found in special teaching methods; in particular as an example of integrating the various disciplines (mathematics, psychology, neurosciences, teaching, anthropology). It could be interesting to consult the text by Biancardi et al. (2003), Franco Angeli, Milano.

[6] With reference to the course *Teaching mathematics for integration* that the author holds at the Faculty of Primary Education Sciences at l'Università di L'Aquila for future, special education teachers who must plan individual courses for children with special needs. The aims of the course can be summed up as follows: to provide a program which integrates mathematical knowledge with disciplinary and pedagogical knowledge in mathematics, which can be applied to the principal difficulties in learning and various disabilities; to help teachers acquire a methodology which includes designing, planning, implementing, testing and evaluating mathematics teaching programs, characterized by a process of abstraction, representation and formalization with reference to a logical-mathematical language; and to cultivate an open attitude towards the mathematics teaching-learning process, by getting teachers to experience standard situations that follow the

Pedagogical research could help reduce the risk of establishing teaching-learning models based on convictions that do not allow for innovation, and have not been tested by rigorous research methodology which ensures its validity and measures its effectiveness (Lucisano and Anna Salerni 2002), as well as providing real processes that are efficient and inexpensive and can be realistically applied in schools.

Psychological research, that in fact goes much further beyond the general reference to Freud, quoted by the author, given the evolution in research and the constructs available[7] for the teacher's use, while at the same time respecting the pedagogic parameters which guarantee that the child's inner world is protected. This can be achieved by concentrating more on the impact from emotional, affective and socio-relational variables[8], rather than increasing the range of activities.

Social questions in relation to which, the paradigm of complexity (Morin 2001), and liquid modernity (Bauman 2009, 2011), provide interpretive keys which project the analysis of mathematical learning needs into a dynamically evolving sociocultural context. As regards to this context, as well as mathematical knowledge, learning processes could also play an important role. For learning mathematics, in its various phases of the learning and growth cycle, requires and also makes it possible to strengthen, as *organization and thought forms*, models and patterns[9] that are useful for the future, as well as providing personal tools to work with.

The communication learning environment sets out to provide a place where the prerequisites can be defined, starting with integrated learning backgrounds which, in a situational approach, can give direction to the process of conception, planning and realization in mathematics teaching environments[10], within a complex system of mathematics teaching methods (Olmetti Peja 2010). These are structured dynamically by connecting phenomena from multiple sources, through which the perspective of educational psychology is currently being redefined.

---

principles of graduality and transcoding, thus helping create learning environments for special needs cases and their teachers.

[7] Mentioned here are some examples referring to themes that have already been intentionally implemented, which guide the process of didactic decision and the organization of the teaching-learning process: multiple intelligences diffusion; self-efficacy; the ego-states, the stimuli and psychology games in class; growth models; the attachment model.

[8] In this regard compare <http://www.eatanews.org/wp-content/uploads/2012/09/ethics-code-feb-13th-edit.pdf>.

[9] In this context, 'pattern' refers to Piaget's use of the term. See Liverta Sempio (1998, p. 150).

[10] An important program was left by the International Commission for the Study and Improvement of Mathematics Teaching (in French CIEAEM, Commission Internationale pour l'Etude et l'Amélioration de l'Enseignement des Mathématiques), founded in 1950, among whose members were the mathematician, educationalist and philosopher, Caleb Gattegno, from the University of London, the French mathematician Gustave Choquet (President) and the Swiss Jean Piaget (Vice-President), psychologist and epistemologist. Using updated teaching methods they attempted to establish a connection between three fields of knowledge which, at that time, were evolving rapidly, in the hope that this would contribute to, "creating a society where people would be able to use mathematical reasoning and its tools to act rationally and develop a capacity for critical thinking, both as citizens and future scientists. Such a humanistic perspective in mathematics education should have been a safeguard against both technocratic behaviour and ideological blindness" (*50 anni di CIEAEM: dove siamo e dove andiamo? Manifesto 2000* per l'anno della matematica) (Fregola 2010a, p. 13).

Mathematics Learning Environments

The term ‘environment’ is used in the broad sense of the word here. To be certain, it indicates a place that is either physical or virtual, where the arrangement and positioning of people is determined by the structure of the place. Technology also plays a significant part in this ‘environment’, and in turn is affected by, and has an effect on, how space and time is organized and conceived.

The concept of environment is meant as a *mental place*, defined via the characteristics of the assignment proposed, which requires specific actions, suitable relational methods and an assessment process which not only takes into account the results, but also the support provided by the teacher (scaffolding) and, in a more general sense, the emotional climate and cognitive styles that come into play, and are also an intrinsic part of the learning environment. In this sense, according to Antonietti (2003), the concept of learning environment overlaps with the concept of setting, by integrating the physical elements inherent in the learning process, the planned objectives and strategies used to achieve them, in an organic and coherent system. Inside this environment, the complementary relationship between teacher and pupil takes shape, which is still an asymmetric relationship type (Carletti and Varani 2007).

It is well known that mathematics, more than other subjects, presents difficulties regarding its structural characteristics that often brings out a child’s anxiety about being unable to learn and triggers *the fear of not being good enough*. This manifests itself into the form of underestimating the worth of mathematics itself, the teacher, the teaching method, and above all the child’s ability to learn (Fregola 2010c). Between 2003 and 2009, we carried out field research which involved roughly 180 children from fourth-grade primary school, from eight classes, followed by about 100 children from third grade, from four classes. The aim of the research was to study the Drivers, studied in Transactional Analysis[11]. Emotional Drivers in Transactional Analysis, are automatisms which can be detected through five behavioural profiles that often go unnoticed. They are neither right nor wrong; they come into play without any intentional control on our part. If there is strong emotional involvement which arises from the situation or the objectives at stake, they are more likely to emerge. It is possible, for the most part, to learn and recognize the Drivers and use the functional aspects that characterize them. The five Driver profiles are as follows: be perfect, make an effort, hurry up, be strong, please people. One of the

[11] Transactional Analysis (TA) is a humanistic-existential branch of psychology, introduced by Eric Berne in the 1950s–1960s. TA is a psychological and social theory based on the philosophy of mutual wellbeing and on a construct that involves studying three ego states of the personality, each of which is defined by Berne as a coherent system of thoughts, feelings and behaviours. The ego states are not roles; they are psychological and phenomenological realities. In every person there are three ego states that are defined as Parent, Child and Adult, which are recognizable according to distinct types of behaviour. Transaction is the unit of social exchange in communication that takes place between people’s ego states. The phenomena that emerge in the process of interaction can be read, partly recognized, and acted on with greater awareness and intention, thus leading to a more effective exchange based on the principle of expressing oneself in the best way possible when relating to another. The effectiveness of TA in education and learning is the subject of substantial research (Montuschi 1993, 1997; Fregola 2011). See also: <http://issuu.com/mathetica/docs/semestrale0>.

assets of Transactional Analysis is the terms it uses, as many of them can set off a process of understanding, also due to the fact that some 'technical' meanings come from everyday language. For example, it is not difficult to assume that meticulous behaviour, extremely precise use of language when speaking and a rigid and upright posture can be traced to the Driver 'be perfect'.

Looking at the teaching-learning process of two-digit division calculations and related research, it was possible to detect that through recognizing the children's Drivers and their own Drivers, the teacher can intervene in order to reduce the negative effects, which manifest as negative emotional states which, in turn, reduce the possibility to organize thinking in an effective way (Fregola 2010b).

For example, the fear of mathematics, the impression of feeling inadequate, the rage towards the teacher, uncertainty, frustration, hostility, and ineffective competition (Fregola 2010a, p. 3).[12] The general hypothesis behind the research is that it is possible to integrate didactic practices that have been consolidated with an approach that takes into account emotional and relational skills, which often go unnoticed by the teachers and students, within a mathematics teaching-learning strategy based on integrating Transactional Analysis in didactic communication models.

It was possible to observe the social dimension that is present in a learning environment, confirmed by the fact that it is "a place where learners may work together and support each other as they use a variety of tools and information resources in their guided pursuit of learning goals and problem solving activities" (Wilson 1996).

Setting Up a Learning Environment[13]

Setting up a learning environment requires keeping various interactive aspects under control, some of which must necessarily be agreed upon with the pupils so that they may become effectively responsible and involved in managing the process. Salomon (1996) systemizes the elements that make up a learning environment:

- physical environment (e.g., spaces available, functional layout of classroom);
- times;
- the participants working inside the environment and relationships which establish the relational and operative climate;
- expectations;
- behaviour, rules, and agreed commitments;
- tasks and activities; and
- tools or artefacts; object of observation, reading, reasoning, manipulation.

These factors must contribute, each one in their own specific way, to organizing environments that should have a series of characteristics, which various authors have attempted to outline (Crismond et al. 2008). Black and McClintock (1996) propose the following key aspects:

---

[12] Research protocol can be found here: <www.mathetica.it>.

[13] As regards to the content of this paragraph, it is worth noting Laura di Giovanni's unpublished thesis: *Videogames and learning environments*, written for the Primary Education Sciences degree course (2010–2011).

- observation of artefacts anchored in authentic situations;
- construction of interpretations based on observations, and constructing arguments for the validity of their interpretations;
- materials contextualisation;
- peer collaboration on the same processes;
- cognitive apprenticeship in observation, interpretation, contextualisation;
- multiple interpretations that enhance cognitive flexibility; and
- gaining transferability by seeing multiple manifestations of the same interpretations.

Regarding this matter, Lebow (1993) indicates the following principles:

- fostering personal autonomy and control over learning by supporting self-regulation, and by proposing subject-matter relevant to the learners;
- creating a learning context that supports the development of personal autonomy and relationships;
- embedding the reasons for learning into the learning activity itself;
- supporting learning feedback, promoting capacities and aptitudes which allow the student to take increasing responsibility for the process of reorganizing his/her knowledge; and
- supporting the learners' tendency to engage in intentional learning processes, thus encouraging the strategic exploration of errors.

In particular, the theory of learning provided by constructivist epistemology has helped define an indicative framework which the teacher can intentionally and consciously draw on when he/she is in the position to plan and create a mathematics learning environment. There are times when traditional educational values (replicability, reliability, communication, control) contrast with the primary values of constructivism (collaboration, personal autonomy, generativity, reflexivity, active engagement, personal relevance, pluralism); but it is precisely for this reason that they can provide precious indications when deciding on teaching methods.

Lastly, according to Savery and Duffy (1996), the principles for planning learning environments should:

- anchor all learning activities to larger tasks or problems;
- support the learner in developing ownership for any type of problem;
- design an authentic task;
- design the task and the learning environment to reflect the complexity of the environment;
- give the learner ownership of the process used to develop a solution;
- design the learning environment to support and challenge the learner's thinking;
- encourage testing ideas against alternative views and alternative contexts; and
- provide opportunity for and support reflection on both the content learned and the learning process.

A conception *of learning*, that focuses mainly on the interpretive activity of the subject, emerges from various factors and models, discarding the concept of *truth* in favour of a consensus gained by comparison and dialogue. As far as the mathematical contents are concerned, this aspect must be emphasized so that the learning process—much as it is personalized and focused on the student so as to promote personal autonomy, self-regulation and control over learning—needs to match the specific formalized level required by mathematical language and by the capacity to master elaborative procedures and problem solving. Nevertheless, with *instructional design*, it is very difficult to fully implement the various principles of constructivism. For these reasons, research today aims to interpret constructivism in many different situations, contexts and content domains. The researchers Carletti and Varani (2007, pp. 32–51) believe that not only are the general features that typify learning environments important, but also some strong core factors which are intertwined in various ways, such as the tools used to organize knowledge, group work, metacognitive reflection, the use of technology and a strong focus on the choice of discipline issues and methods of evaluation.

Thus, from the factors that have been highlighted (Carletti and Varani 2007, p. 31), it emerges that the definition of a learning environment that takes into account the characteristics of mathematics[14] requires a vast repertoire of skills and approaches. It requires researching borderline fields of integration between different disciplines; it shifts in the direction of renewed methodological rigour, which is able to synthesize the contributions coming from different science disciplines, starting with its own epistemology, and phenomena that can directly or indirectly affect the process of mathematics teaching-learning. Thus, the choices that govern the conception, planning and use of learning environments require the teacher to focus his/her attention and decision-making process on aspects that have already been altered due to a process of change, which involves the integration between tradition and innovation.

More specifically, all this requires renewed attention to a variety of relative notions, namely:

- learning;
- the role of the learner;
- the social dimension;
- the dimension of organizational and financial resources of the school;
- ways of structuring the task environment; and
- developing self-awareness about the knowledge-building process.

These aspects provide the opportunity to support the intentions that drive the learning process by organizing activities that contain the reasons for learning, boost intrinsic motivation and encourage exploration in the student's own learning growth. This can give rise to remarkable results; learning mathematics enhances cognitive, metacognitive and affective abilities, which encourage reflection and monitoring of the material learned and the methods used to promote a sense of self-efficacy and autonomy (Fregola 2011).

[14] In the introduction to their book, *Pensare in Matematica*, Isdrael and Millán Gasca (2012), write: "…teaching base concepts in elementary form requires mastering their subtleties and the countless difficulties that have been addressed over centuries of reflection and elaboration. What is directly taught to children may seem like nothing much in terms of the amount of concepts and methods used, but the clarity and effectiveness of the teaching comes from a background of in-depth understanding that, even though it remains behind the scenes, plays a decisive role".

Simulation Games and Learning Environments

Angela Piu writes:

> Planning a simulation game for mathematics learning in primary school may involve preparing an accurate representation or model from real life that presents a problematic situation which can lead the children to activate a process of construction and discovery guided by mathematical concepts, rules or structure. The interaction with the real life model takes place by assuming roles that require carrying out specific actions, activating behaviour that is coherent with the context of the task in question and manipulating material that has been organised according to the rules and aims of the game. (2010, pp. 112–130)

In a simulation game, a scenario is constructed by reducing the complexity of the real-life situation to its salient aspects, and the characters are established along with some rules. The scenario changes continuously as the game evolves. The participants interpret the characters and own objects which are useful for that context. The roles that are interpreted and the objectives to be reached are based on predefined rules that indicate the limits and the amount of freedom that the child can work with without violating the rules of the game. The strategies represent a combination of different possible solutions and moves with the players, who are immersed in the situation and 'identify' with the part that can achieve their aim. The rules guarantee that the game unfolds in a 'coherent' fashion and establish the type of moves that can be made. However, as the game is carried out, the players' capacity to interpret the role emerges, which also brings out unwritten socio-relational rules that are shared or pertinent to the needs of that given context. The phases and actions are organized as the simulation develops and have been established in the rules beforehand, as already explained.

The representation of different situations and role changes, instead, allow for the exploration of new reasons and perspectives, helping to change points of view and attitudes.

The Component Parts of a Simulation Game Project

Planning and setting up a learning environment where learning mathematics takes place is determined and defined by various elements, namely: the educational aims, the learning objectives and nature of the content along with the specific characteristics of the students and the schools' organizational constraints.

When planning and setting up a simulation game, due to the nature of its component parts, one requires his/her own nature to take a creative approach which must be developed within the context of a complex methodological background. This explores the educational psychology models that can lend rigour and legitimacy to planning and operative decisions, which also take into account the characteristics of relational interaction (Fig. 1). Here are some examples:

- there is a difference if the specific contents refer to *understanding* a mathematical concept, rule or structure, rather than *memorizing* it, which means that there is *knowledge* (Bloom 1983) about how they are expressed specifically in formal mathematics language;

Fig. 1 These pictures were used with children from the 2nd year of primary school as a stimulus to get them to distinguish between regular and irregular images during a simulation game, whose purpose was to introduce the concept of area and surface area, space and volume

- there is a difference between whether one intends to *apply* the concept, rule or structure in problem solving situations or have them recognized in real contexts instead;
- there is a difference between a simulation game that involves using the computer and one that uses a real-life situation with concrete materials or materials that have been set up for the task beforehand; and
- there are differences between a game that is designed for a single student and one that involves working in a group (Gentile 1998, 2000, 2008).

Despite the variety that exists among the different simulation games, they are all based on certain specific elements.

1. **Aims:** they represent the perspective for educational values, for general cognitive skills and abilities that one sets out to foster and develop in the pupils.

2. **Learning objectives:** the cognitive performance that pupils must be able to produce in response to mathematical contents which refer to concepts, rules, procedures, processes, structures, and models.
3. **The simulation model:** The definition of a model gives necessary structure to the chosen simulation.
4. **The setting:** the context in which the simulation takes place, namely, where the dynamics of the simulation are carried out and worked on by those taking part. It is used to establish the 'reality space' in which the action takes place, which helps to give a clearer definition to the roles assumed by the protagonists, since it helps to make the essential relationships and characterizations of the roles more explicit.
5. **Subject area or problematic situation:** the subject or the problematic situation being addressed, which the participants in the simulation activity have to tackle.
6. **The purpose of the game:** the operative goal that the participants can reach through the actions and strategies they will adopt and put into practice.
7. **The roles:** the participants, as protagonists and actors, who will have to interpret various circumstances by tackling the well-structured and sometimes complex situations provided by the games. The roles played are exactly those mentioned, a part of the structure of the game, which are assumed by the participants. These can be assigned—rigidly defined by rules and objectives from the very beginning—or they can be functional, which means that they take shape as the action unfolds on the basis of a general indication of the objectives, so they are liable to change during the course of the game.
8. **The documents:** used to provide information clearly, with reference to:

   - the roles to be played and possible introduction of other roles;
   - the setting;
   - the principal problem and any other difficulties that may come up during the simulation;
   - rules of conduct, how much power they are allowed, strategies that are not permitted; and
   - time and spaces.

9. **The materials:** can be used in the manipulation activities in the simulation game and function as intermediaries between reality and the world of mathematics. As well as providing a concrete reference for mathematical concept, they are also concrete models which are more abstract than the perceived situation, and less abstract than formal symbols (AA VV 1965; Dienes 1971; Post 1971). The materials can be taken from already existing materials or can be implemented or created especially for the game, in cases where suitable materials for the simulation game are not commercially available. If one decides to create prototypes of materials, it is necessary to pay attention to the constraints imposed on producing these materials, in terms of the time it takes to produce them, technological factors, and human and financial resources.

10. **Materials for the role-play:** specific tools may be used during the role-play (e.g., maps, relief maps, posters, charts, cards) in order to give the participants all the necessary information provided by direct experience. They can be used to represent the simulation and, as the activity unfolds, to show the effect produced by different decisions taken during the game.
11. **Assessment system:** includes assessment criteria on the basis of which a 'score' is applied to the various results produced by the participants' actions during the game. It is virtually a method which shows the results of most of the decisions made during competitive games or games with a lot of restrictions, where the rules carry a lot of weight.
12. **The final discussion (or debriefing):** the concluding summary stage. After the activity has taken place, the final discussion makes it possible to put the simulation in the right perspective, it ensures that the experience is made good use of and is brought into full awareness. The moment of discussion is a key element in that it allows the participants to discuss the results, to compare different opinions and analyze the results achieved and actions taken, so as to analyze, systemize and generalize the contents and mathematical processes which were dealt with during the game. The debriefing can be organized in a number of different ways, from an informal discussion to a structured one, to other forms of reports or written comments about the experience.
13. **Assessment:** the gathering and analysis of data which allows one to establish whether, and to what extent, the set goals were achieved, namely: whether the activity brought about the changes (as regards to knowledge, attitude, and abilities), which were originally proposed in the list of objectives. It also concerns ways of checking the simulation process through using checklists that provide the process descriptors and indicators of single items of knowledge, abilities and skills that portray the concepts, rules, processes, structures and models that one aims to reveal and define in mathematical language. Another object of assessment can be the emotional aspect, the motivation in terms of participation and involvement.

Are Video Games Learning Environments for Mathematics?

It is complicated to make generalizations about this issue in that there is a wide range of video games available on the market and web portals and, to be sure, some of them are for didactic use. Nevertheless, it is evident that the aim of video games is to entertain and there is no explicit indication that one can take into consideration, tout court, a deliberate focus on learning[15], at least as far as formal scholastic

[15] It is interesting observing that the Anglo-Saxon neologism *edutainment* is a fusion of the two words 'educational' and 'entertainment', and expresses the fundamental principle of video games that can enable *learning through playing.*

learning is concerned. During our research, we established that there are at least two functions that can be assigned to video games: (a) defining a learning environment for mathematics concerning calculations, counting, exploring space, problem solving, and decision-making processes; and (b) defining learning environments which concern *learning processes* that are useful for learning mathematics.

From a structural and functional point of view, video games meet many of the requirements that are necessary to be used as learning environments. But before they can be used in this way, they must be inserted into a design process specifically constructed with explicit aims in mind in order to become a tool that informs the students and makes them aware. It is common knowledge that students spend a lot of their time playing video games; it is an activity that challenges and provokes them, is highly stimulating and allows them to search and create problem solving strategies and decisions, and above all, gives structure to the time spent playing.

We asked ourselves what motivated students to spend time on such an exclusive and engrossing activity as video games[16]. Caillois (2000), referring to the game in itself, maintains that people only play these games if they want to, when they want to, and for as long as they like, and that if they were obliged to take part in a game it would immediately cease to be one, in that it would turn into an obligation. Moreover, it would lose its fundamental characteristics, namely, the fact that the players devote themselves to the game spontaneously and for the sole purpose of enjoyment, having the freedom, every time, to choose rest or a productive activity. This observation leads one to the reflection that if video games are to keep the specific qualities of the two possible functions for developing learning, it is necessary to create a relational approach that does not lead to the paradox "be spontaneous" (Wazlawick 2008). The order indicated by the imperatives "you must!" and "Be!" is incompatible with the concept of spontaneity. If, for example, the teacher instructed students to play video games "to develop problem solving skills", it would be asking them to *obey* by being spontaneous. This natural and legitimate behaviour would turn into a sort of paradox that would diminish the magic and playful aspects of the game. Thus, integrating video games into a learning environment requires using skill that comes from a methodology which regulates forms of interaction and relational exchanges between the students.

Caillois subdivides traditional games on the basis of four broad categories, according to the level of competition present, along with chance, mimicry or vertigo that he calls, respectively: Agon, Alea, Mimicry, and Ilinx.[17] Maybe some other categories are necessary, for those games that can restore the sense of feeling able to make decisions, resolve, learn and coordinate emotional, cognitive, metacognitive,

[16] To study this interesting new field more deeply, compared to Aarseth (2001).

[17] The Latin word *Agon* is the spirit of competition; *Alea* indicates the game of dice. The players are completely passive in that victory is only a matter of destiny; there is no ability skill, patience, or training involved. *Mimicry* (the mimicry of insects) for the author, this can be found in man's love of disguising himself, dressing up, wearing a mask, and playing a part. Games involving illusion or an imaginary aspect come under this category. *Ilinx* is the last type of games which are based on the quest for a sense of vertigo.

psychomotor and relational aspects in one single environment, that provides immediate feedback and allows one to connect the results with one's own inner dialogues. In fact, the motivation for playing video games, their limits and strong points, the risks and opportunities that they bring to the learning process and educational processes, depend both on the type and characteristics of the video games, and on the context and the relational contract that the teacher…and the parents can propose (Mangia 2009).

All of this provides a whole range of possible explanations, as well as the search for new explanations concerning phenomena which as yet have no references about the outcomes, effects or results that using video games can have on the processes of mathematics learning. As a matter of fact, most video games, a little like the traditional game Snakes and Ladders[18], entail a process where a goal must be reached, full of challenges to overcome that call for reflection, memory, the discovery of new knowledge, along with further questions which one must find the answers to. Very often, the places and times in which the characters move are reconstructions of geographic places and historical periods, futuristic and fantasy settings. During a video game session the player's logic skills, which are needed to move through the maze-like stages of the game, are continuously stimulated, representing a real stimulus for the mind (Gardner 1999, 1995, 1989). Children can perform a complex activity which, on reaching the final goal, "provides rapid and immediate gratification, which serves to boost self-esteem and self-confidence" (Maragliano et al. 2003).

Some Skills and Abilities Which Are Covertly Developed and Stimulate the Mathematical Mind

Observing children play a number of video games that have some connection, directly or indirectly, with mathematical content, it was possible to notice how, during a video game session, many factors come into play involving skills and abilities that belong to the mathematics learning process.

Here is a suggested list that is still in the development phase:

- ability for abstract thinking;
- ability to make generalizations;
- sense of logic;
- critical thinking skills;
- ability to analyze;
- ability to synthesize information;
- coding, decoding, transcoding abilities;
- transfer skills;
- problem solving abilities;
- capacity to make choices; and
- capacity to make decisions in uncertain situations.

[18] Compared to Marrone (2009).

For example, many video games and simple simulation games[19], which gradually become more complex in terms of mental calculation and calculation skills[20], can be found on the Internet. Depending on the objectives that determine the choice of video game, it is possible to focus on one or more abilities or skills. The video game in Fig. 2 was used to stimulate analysis skills and to develop abilities for coding, decoding, transcoding numerical symbols, and correctly solve arithmetic operations.

Ability: to resolve operations correctly and quickly
Content: rapid mental calculation
Age: 7 years and upward
Speed: slow normal fast
Result: from one figure from one or two figures
Operations: …. all ……

Fig. 2 The wolf and the hare

[19] Some games have been included in an interesting paper Nesler (2007).

[20] See, for example: <http://www.matematicamente.it/giochi_e_gare/gioca_con_la_matematica/lupo_e_lepre%3A_calcolo_mentale_rapido,_7%2B_anni_200804113058/>.

The ways in which these abilities and skills are expressed during play are many and varied. Some of them can be observed directly, others indirectly, through intercepting variables which makes it possible to understand the specific abilities or skills being used, in any case, it is possible to pin down the indicators which help the teacher to recognize them. By indicating one or more of these skills or abilities as the specific aim of the game, it is possible to intentionally focus on the function that the game itself can provide in the learning process.

In our opinion, so that a teacher may intervene to influence the learning process without "breaking the spell of playing", two conditions are necessary. First, because it is necessary to have experience in the psychology of learning which allows one to draw on theoretical references that can guide the decision-making process for teaching and the actions taken as a consequence. Secondly, in order to carry out intentional observation, it is necessary to avail oneself of specific tools that are provided by research methodology and experimental pedagogy. However, suitable training is needed in order to use them properly, which does not come from knowledge but from specific experience in this field. For example: the *ability to analyze* can be measured by observing the child during play, he/she identifies the information present in different formats and languages and uses them to structure a choice, to reach a goal provided by the game model. He/she compares the different alternatives available by making appropriate assessments in terms of the relationship between cost/benefit, efficacy/efficiency, the effectiveness of actions taken in order to complete the model and go on to the next one.

Measuring the *ability for abstract thinking* requires a more complex definition of indicators. An approach we were able to experiment with, related to a transcoding pattern, is given in the following:

- Level 1: phrases are used with some references to the concept, rule, structure;
- Level 2: some examples or phrases are used that refer to the concept, rule, structure in order to explain it;
- Level 3: a connection is established between the concept, rule, structure, by relating it to a sensory-motor level: actions, manipulation of everyday objects;
- Level 4: the concept, rule, structure is referred to using references to the formal process that may represent them; and
- Level 5: the concept, rule, structure is referred to using mathematical language and an explanation is provided in student's own words.

Is Gagné's Hierarchy Still Relevant Today?

A contribution towards educational programming, which entails the use of video games, can be found through examining and carrying out an integrated reworking of Gagné's hierarchy (1973). The original definition given in Gagné's hierarchy of learning is a set of specified intellectual capabilities that have a relationship to each other, and these possible relationships are highlighted by using a specifically designed learning task.

Every hierarchical block contains the description of a capability and the formulation of every capability is expressed in behavioural terms (i.e., it indicates, as precisely as possible, what type of behaviour must be expressed by the student who is using *that particular skill*). For Gagné it is not enough to define the abilities and knowledge to be put into practice; it is necessary to identify the relationship order between them which allows for optimal progression that gives structure and form to the teaching process. In a traditional learning environment, task analysis refers to the possibility and prospect of subdividing a subject and a wider-ranging set of objectives with a series of intermediary activities which are more limited and more easily transferred to educational procedures. In an environment where video games are used, one possible way of developing this analysis is by resorting to a retrospective construction of a learning hierarchy that represents a 'network' of concepts, rules and structures that are found in video games. The skills are considered to be hierarchically connected if, while learning one of them during a specific task, the one that is deemed 'easier' produces a positive transfer for the one that is considered more difficult. According to another interpretation, two skills are considered to be hierarchically connected if, by being able to use one of them during a task, the more complex one, one can use the other one that is considered less complex. In either case, the key elements can be attributed to positive transfer, along with the fact that one skill is needed in order to acquire another one. Leaving aside the nature of a video game, it is evident that the child's immersion in the game moves along two axes that we have defined the analysis/synthesis axis and the problem solving/decision-making axis. Gagné's hierarchy has provided a useful support tool to help define the beginnings of a broader hierarchy, which has been integrated by our observations and can serve as a guide to pinpointing the capabilities that are used during a video game.

It is true that we focused on video games, but the real purpose is to study video games in order to connect the affinities and isomorphism between playing video games and educating a mind that generates mathematical thinking and, as we say in the mathematics field….vice versa.

The most important aspect to underline here is that the levels of Gagné's hierarchy were formed in relation to the learning theories around at that time. Gagné's model aimed to integrate learning theories with the choice and definition of teaching strategies in a way that allowed for the variables[21] investigated by every theory, which have an effect on the decision-making teaching procedure. However, Gagné's model does not explicitly consider the metacognitive processes, the relational dynamics of affective and emotional variables that can exist in a communication learning environment. This is also due to the way that research has evolved which, in

[21] This refers, in particular, to the variables identified by Bloom (1972, 1979), when setting out his theory of scholastic learning: cognitive input capacities, affective characteristics and quality of education. The quality of education is the variable that is closely linked to teaching skills, which allow the teacher to contribute to and encourage learning by using the input variables and the capacity to analyze and plan the teaching.

the early 90s, had not yet started to define certain constructs related to sociocultural variables and Gardner's[22] multiple intelligences. For this reason we integrated into our work some dimensions relating to the study of variables which, even though they have always been part of the communication learning environment, were not as yet observed by using theories of reference that were only introduced more recently. At the same time games and gaming (Huizinga 2002) did not have virtual environments and the natives were not yet *digital natives*.

The following shows the key aspects of intellectual abilities indicated in Gagné's hierarchy in a list that does not claim to cover everything, but indicates, in particular, some examples of basic mathematics terms. Tables are a tool and can be used as a guide in the design of a video game as a learning environment. In fact video games activate factors that remain hidden. Teachers/students are not always aware of the function that these factors have in the learning teaching process.

Intellectual Dimension

- **Discrimination:**[23] distinguishing between different parts of the environment, colours, shapes, different sizes, measurements, structures and distances.
- **Concrete concepts:**[24] analytical skills, recursiveness, consistency, observation skills, classification skills, recognizing and using quantities, understanding and using [geometric shapes, different sizes, measurements, spatiotemporal indicators].
- **Regole:**[25] calculating skills, capable of using mathematical language, spatial perception organization skills; understanding and using symbolic language, and understanding the semiotic language proposed in the game.
- **Higher-order rules/problem solving:**[26] ability to make abstractions, capacity to synthesize, capacity to make choices, strategies and learning through trial-and-error, logical thinking skills, resolving problems by using problem solving strategies, knowing the interface and purpose of the game, asking questions, knowing how to analyze and resolve problems autonomously.

Observing the behaviour of differently aged children, while they were playing video games, it was possible to identify some skills/abilities they used. These are often used by children without them being self-aware. The hypothesis is that these abilities are the same ones needed to learn concepts, rules, and mathematical structures. Thus, consequently, they can be stimulated and potentiated with a guided use of video games. We are certainly talking about selected games. The skills/abilities we are referring to belong to the cognitive, psychomotor, metacognitive and socio-relational dimensions of the learning process.[27]

---

[22] Compared to Footnote 7.

[23] Compared to Gagné (1973), from p. 193.

[24] Compared to Gagné (1973), from p. 210.

[25] Compared to Gagné (1973), from p. 249.

[26] Compared to Gagné (1973), from p. 257.

[27] A relevant contribution has been provided by Laura Di Giovanni and da Maria Eledia Mangia. The idea and the initial findings come from observations I made while watching my sons playing video games.

Cognitive Dimension

Coding-decoding-transcoding skills; making decisions in uncertain situations; analyzing the material proposed in the game; taking prompt action; always proceeding in a consistent manner; experiencing the cause-effect relationship; checking decisions that have been made; working out the rules of the game; understanding and following procedures and rules of the game; setting off inference processes; setting off induction processes; identifying the objective of the game; exploring worlds that are imaginary or distant for the player; narrating video game experiences; collecting and elaborating information through visual activities; managing interdependent variables; managing different information and different types of information at the same time; using selective attention; realizing spatial integration; understanding and mastering depictions of reality; managing images in a two-dimensional space; using serial processes; spotting and recognizing obstacles by understanding their nature; distinguishing the figures from the setting by concentrating on the scene and place where the action unfolds rather than on weak identifying signals provided by symbols, objects; paying attention to the moving images on the screen; analyzing sounds; reading and understanding instructions; letting oneself be led by one's imagination; adopting different points of view; selecting and recognizing objectives in order to reach the next levels; single actions (managing time, organizing space); bodies of knowledge (reactivating previously acquired information and knowledge; explaining the plot of the virtual story; understanding iconic and spatial requests; dealing with symbolic systems).

Psychomotor Dimension

Eye-hand coordination; combined variations of fine motor movements of fingers and hands; combination of different types of information (visual, tactile, proprioceptive, lexical semantic, musical) that generate plans of action which, on reaching a satisfactorily efficient level, are stabilized, represented 'mentally' and memorized; pairing and combination of movements; automization of movements through using conscious control while tactically managing movement; anticipation and Reaction [space] (forwards/backwards, right/left, near/far, inside/outside, above/below, long/short, high/low, wide/narrow, open/closed, large/small); anticipation and Reaction [space] (before/after, at the same time, fast/slow).

Metacognitive Dimension

The video games proposed encourage the player to ask questions and make decisions; they foster planning skills and enable the player to make a retroactive check of the mental route taken during the playing of the game. They develop and increase meta-memory skills, namely, awareness of strategic behaviour and memory systems that are activated during the game; they trigger a self-regulatory process which involves controlling and adjusting strategies on the basis of previous knowledge. From this, one can deduce that the use of video games leads to the development of metacognitive skills such as: identification of the elements that he/she is about to deal with (comprehension); awareness of one's own strategies, own resources and resources available, and possible application thereof (estimation and forecasting); strategy planning (planning); control and supervision of performance (monitoring); results assessment; self-regulatory feedback on game process.

Socio-Relational Dimension

Peer comparison; formulating questions; providing answers; regulating and understanding one's own and others emotional states; narrating the video game experience; asking for help; knowing how to ask for collaboration and cooperation in order to pursue the objective; knowing how to communicate effectively and efficiently.

It has been observed that the presence of a finishing line and multiple difficulty levels are among the main attractions of video games. Moreover, the range of difficulty and the stimulating situations have a motivating effect which activates agency, resilience and the search for increasingly time-saving strategies.

Learning Environments and Education of the Mind Within a Complex System

Roughly 30 years ago, Lucio Lombardo Radice (1986, p. 147) wrote:

> The Wright brothers' biplane, Guglielmo Marconi's crystal radio set, the Lumières' cinema, the ultramodern representatives of the youth of the fathers of that time, are seen by our children as belonging to an archaeological museum. For them Enrico Fermi's wonder from 20 years ago, the atomic pile, has the patina of an ancient monument. Even mathematics, even "divine" and "perfect" geometry have had their foundations renewed, developed and revolutionised, so that excellent formalist teachers, trained in modern teaching 20 years ago, have to study everything from the beginning again in order to come into line with the new programmes for their pupils.

He concludes by highlighting the necessity to plan an education for the mind. Many years have passed since the publication of the book by Michele Pellerey (1983), *Per un Insegnamento della Matematica dal Volto Umano* (*For mathematics teaching with a human face*). I often discover in those pages, between the lines, the outlines for defining and managing learning environments, that, besides having a human face, deal with technology and the web 2.0. As things happen during the interaction between teacher and child, the teacher is often unaware of their behaviour, thoughts, emotions and reference systems that stimulate behaviour, thoughts and emotions which cross the border line between the child's external world and inner world who, in turn, is constructing his/her own frame of reference.[28] Learning environments stimulate learning for abstraction and for immersion, and one could put forward a hypothesis that mathematical language could be considered the beginning of a journey distributed over time, in relation to which the terms 'concrete' and 'virtual', which gradually change form, become the 'frames' of a semantic network (De Keckhove 1991), whose most efficient expression coincides with the child being able to master all of the significant mathematical constructs. In this way, the development of 'mathematical thinking' can be understood as constituting a set of necessary skills for handling mathematical learning in the most varied scopes of application and within a system of self-regulating skills to be used in the child's own learning process. Indeed, the redefinition of the sense of identity and belonging, and as a result, the relationship each person has with their own learning, is already underway (Fregola and Iozzelli 2013).

References

AA VV. (1965). *Il materiale per l'insegnamento della matematica*. Firenze: La Nuova Italia.

Aarseth, E. (2001). Computer game studies, year one. *Game Studies,* 1(1).

[28] In this context, Frame of Reference is seen from a Transactional Analysis point of view. It is a construct introduced by Jaqui Schiff, written up by Viene, which is defined as a structure of associated responses that integrate the different ego states in response to specific stimuli. It provides a person with a perceptive, conceptual, affective system, as well as one of action, and is used to define the Self, Others, the World … the perception of the self that is learned.

Antonietti, A. (2003). Contesti di sviluppo-apprendimento come scenari di scuola. In C. Scurati (Ed.), *Infanzia scenari di scuola* (pp. 31–56). Brescia: La Scuola.
Bandura, A. (2000). *Autoefficacia: teoria e applicazioni*. Trento: Erickson.
Bauman, Z. (2009). *La solitudine del cittadino globale.* Milano: Feltrinelli.
Bauman, Z. (2011). *Modernità liquida*. Bari: Laterza.
Biancardi, A., Mariani, E., & Pieretti, M. (2003). *La discalculia evolutiva: dai modelli neuropsicologici alla riabilitazione.* Milano: Angeli.
Black, J., & McClintock, R. (1996). An interpretation construction approach to constructivist design. In B. Wilson (Ed.), *Contructivist learning environments: Case studies in instructional design* (pp. 25–32). Engelwood Cliffs: Educational Technology Publications.
Bloom, B. S. (1972). *Conseguenze affettive del profitto scolastico*. In J. K. Block (Ed.), *Mastery learning*. Torino: Loescher.
Bloom, B. S. (1979). *Caratteristiche umane e apprendimento scolastico*. Roma: Armando.
Bloom, B. S. (1983). *Tassonomia degli obiettivi educativi, La classificazione delle mete dell'educazione: Area cognitive* (Vol. 1). Teramo: Giunti & Lisciani.
Brousseau, G. (2008). *Ingegneria didattica ed Epistemologia della Matematica*. Bologna: Pitagora editrice.
Caillois, R. (2000). *I giochi e gli uomini. La maschera e la vertigine*. Bologna: Bompiani.
Camaioni, L., & Di Blasio, P. (2007). *Psicologia dello Sviluppo*. Bologna: Il Mulino.
Carletti, A., & Varani, A. (2007). Progettare e gestire ambienti di apprendimento. In A. Carletti & A. Varani (Eds.), *Ambienti d'apprendimento e nuove tecnologie. Nuove applicazioni della didattica costruttivista nella scuola* (pp. 28–29). Trento: Erickson.
Castelnuovo, E. (1964). *Didattica della Matematica*. Firenze: La Nuova Italia.
Courant, R., & Robbins, H. (1972). *Che cosa è la matematica. Introduzione elementare ai suoi concetti e metodi*. Torino: Boringhieri.
Crismond, D., Howland, J., Jonassen, D., & Marra, R. M. (2008). How Does Technology Facilitate Learning? *Education.com.* http://www.education.com/reference/article/how- does-technology-facilitate-learning/. Accessed 9 Dec 2012.
D'Amore, B. (1999). *Elementi di didattica della matematica*. Bologna: Pitagora.
De Keckhove, D. (1991). *Brainframes, Mente, Tecnologia, Mercato. Come le tecnologie della comunicazione trasformano la mente umana*. Bologna: Baskerville.
Devlin, K. (2003). *Il linguaggio della matematica. Rendere visibile l'invisibile*. Torino: Boringhieri.
Devlin, K. (2005). *L'istinto matematico, perché sei anche tu un genio dei numeri*. Milano: Raffaello Cortina.
Devlin K., (2007). *L'istinto matematico. Perché sei anche tu un genio dei numeri.* Milano: Raffaello Cortina.
Dienes, Z. P. (1971). *Le sei tappe del processo d'apprendimento in matematica*. Firenze: Organizzazioni speciali.
Fregola, C. (2010a). Epistemological framework and mathematical learning. In A. Piu & C. Fregola (Eds.), *Simulation and Gaming for Mathematical Education: Epistemology and Teaching Strategies* (pp. 1–14). Hershey: IGI Global.
Fregola, C. (2010b). Mathematical calculation procedures and drivers in action in the learning environment. *International Journal of Transactional Analysis Research, 1*(1), 30–39.
Fregola, C. (2010c). Simulation games and emotive, affective and social issues. In A. Piu & C. Fregola (Eds.), *Simulation and Gaming for Mathematical Education: Epistemology and Teaching Strategies* (pp. 57–64). Hershey: IGI Global.
Fregola, C. (2011). Analisi Transazionale e processi educativi. Esplorazioni per curiosare nel Campo Educativo nella complessità sociale e culturale del nostro tempo. In E. Tangolo & P. Vinella (Eds.), *Professione Counsellor, Competenze e prospettiva nel counselling analitico transazionale.* Pisa: Felice Editore.
Fregola, C., & Iozzelli, A. (2013). Transactional analysis in relation to one's own learning process and strategical study. *International Journal of Transactional Analysis Research, 4*(1).
Gagné, R. M. (1973). *Le condizioni dell'apprendimento*. Roma: Armando.
Gardner, H. (1989). *Formae mentis*. Milano: Feltrinelli.
Gardner, H. (1995). *L'educazione delle intelligenze multiple: dalla teoria alla prassi pedagogica*. Milano: Anabasi.

Gardner, H. (1999). *Sapere per comprendere, Discipline di studio e disciplina della mente*. Milano: Feltrinelli.

Gentile, M. (1998). Apprendere geometria euclidea con il Cooperative Learning [Learning Geometry with Cooperative Learning]. *ISRE, 5*(3), 43–58.

Gentile, M. (2000). Concezioni d'intelligenza, sviluppo motivazionale e apprendimento [Personal theories, intelligence, motivational development and learning]. *Psicologia dell'Educazione e della Formazione, 2*(3), 341–351.

Gentile, M. (2008). Nuove tecnologie e apprendimento cooperativo. [Learning with technologies and cooperative learning]. *Scuola e Formazione*, pp. 21–25.

Heritage, M. (2007). Formative assessment: What do teachers need to know and do? *Phi Delta Kappan, 89*(2), 140–145.

Heritage, M., Kim, J., Vendlinski, T., & Herman, J. (2009). From evidence to action: A seamless process in formative assessment? *Educational Measurement: Issues and Practice, 28*(3), 24–31.

Huizinga, J. (2002). *Homo ludens*. Torino: Einaudi.

Isdrael, G., & Millán Gasca, A. (2012). *Pensare in Matematica*. Bologna: Zanichelli.

Kline, M. (1985). *Matematica la perdita della certezza*. Milano: Mondadori.

Lebow, D. (1993). Costructivist values for instructional systems design: Five principles toward a new mindset. *Educational Technology Research and Development, 41*(3), 5.

Liverta Sempio, O. (1998). *Vygotskij, Piaget, Bruner. Concezioni dello sviluppo*. Milano: Raffaello Cortina.

Lolli, G. (2002). *Filosofia della matematica: L'eredità del Novecento*. Bologna: Il Mulino.

Lombardo Radice, L. (1986). *L'educazione della mente*. Roma: Editori Riuniti.

Lucangeli, D., Iannitti, A., & Vettore, M. (2007). *Lo sviluppo dell'intelligenza numerica*. Roma: Carocci.

Lucangeli, D., Poli, S., & Molin, A. (2011). *Sviluppare l'intelligenza numerica*. Trento: Erickson.

Lucisano, P., & Anna Salerni, A. (2002). *Metodologia della ricerca in educazione e formazione*. Roma: Carocci.

Lévy, P. (2005). *Il virtual*. Milano: Raffaello Cortina.

Mangia, E. (2009). *Il bambino reale nel mondo virtuale dei videogiochi* (Newsletter). Didamat, Master in Didattica della Matematica fra arte, scienze e realtà, Università Roma Tre.

Maracchia, S. (1975). *La matematica come sistema ipotetico-deduttivo*. Firenze: Le Monnier.

Maragliano R., Melai, M., & Quadrio, A. (2003). *Joystick* [Pedagogia dei videogame]:(p. 47) Milano: Walt Disney Company.

Marrone, G. (2009). *Giocattolando. Il bambino ludico: dal gioco dell'oca ai videogiochi*. Roma: Edizioni Conoscenza.

Montuschi, F. (1993). *Competenza affettiva e apprendimento*. Brescia: La Scuola.

Montuschi, F. (1997). *Fare e Essere*. Assisi: La Cittadella.

Morin, E. (2001). *La Natura della Natura. Il metodo*. Milano: Raffaello Cortina.

Nesler, R. (2007). *Imparo giocando: videogiochi e apprendimento*. Trento: Provincia Autonoma di Trento.

Olmetti Peja, D. (2007). Diventare studenti strategic. In C. Fregola & D. Olmetti Peja (Eds.), *Superare un esame: Come trasformare ansia, emotività e studio in risorse strategiche*. Napoli: EDISES.

Olmetti Peja, D. (2010). Towards the construction of a system of maths teaching. In A. Piu & C. Fregola (Eds.), *Simulation and gaming for mathematical education: Epistemology and teaching strategies* (pp. 15–24). Hershey: Idea-Group Inc.

Pellerey, M. (1983). *Per un insegnamento della matematica dal volto umano*. Torino: SEI.

Perini, S. (1997). *Psicologia dell'Educazione*. Bologna: Il Mulino.

Piu, A. (2010). Design of a simulation game for the learning of mathematics. In A. Piu & C. Fregola (Eds.), *Simulation and gaming for mathematical education: Epistemology and teaching strategies*. Hershey: Idea-Group Inc.

Post, T. (1971). The role of manipulative materials in the learning of mathematical concepts. In *Selected Issues in Mathematics Education* (pp. 109–131). Berkeley: National Society for the Study of Education and National Council of Teachers of Mathematics, McCutchan Publishing Corporation.

Prensky, M. (2001). *Digital natives, digital immigrants*. Retrieved from http://www.marcprensky.com. Accessed May 2013.
Resnick, L. B., & Ford, W. W. (1981). *Psicologia della matematica e apprendimento scolastico*. Torino: SEI.
Rivoltella, C. (2012). *Neurodidattica. Insegnare al cervello che apprende*. Milano: Raffaello Cortina.
Salomon, G. (1996). Studying novel learning environments as pattern of change. In S. Vosniadou, E. De Corte, R. Glaser, & H. Mandl (Eds.), *International perspectives on the psychological foundations of technology-based learning environments* (pp. 363–377). Mahwah: Erlbaum.
Savery, J., & Duffy, T. (1996). Problem based learning: An instructional model and its constructivist framework. In B. Wilson (Ed.), *Constructivist learning environments. Case Studies in instructional design* (pp. 135–148). Englewood Cliffs: Educational Technology Publications..
Wazlawick, P. (2008). *Istruzioni per rendersi infelici*. Milano: Feltrinelli.
Wilson, B. G. (1996). *Constructivist learning environments: Case studies in instructional design* (p. 5). Englewood Cliffs: Educational Technology Publications.

Cesare Fregolais Professor of *Didactics of Mathematics for the Integration* in the Faculty of Primary Education at the University of L'Aquila in Italy. He also leads the Experimental Pedagogy Laboratory at the Università Roma Tre of Rome, Italy. He is a PTSTA (E) Provisional Teaching and Supervising Transactional Analyst in Educational field for the EATA (European Association Transactional Analysis). Cesare led and currently participates in research on emotional, cognitive, meta-cognitive and socio-relational dimensions in the learning processes of mathematics as well as for the design, and realization of learning environments for lifelong learning. He has authored monographs, articles and papers of both national and international relevance. He has also co-edited (along with Angela Piu) and written a number of chapters in the book, *Simulation and Gaming for Mathematical Education: Epistemology and Teaching Strategies* (IGI Global, 2010).

Serious Games and Gaming

Terry Bossomaier

Abstract This chapter studies serious games, games for education and training. First, the nature of what makes a game is discussed and a distinction drawn between games and simulation. Games are considered at multiple levels. At one level, there are games which focus on developing a physical skill, such as learning to fly a plane or carry out a surgical procedure. At other levels are games which develop high-level social skills and gamification, the addition of game-like elements to add motivation. The progress in developing games for mathematics education is described, along with a general perspective on the state of evaluation of serious games.

Keywords Collateral Learning · Culture · Play · Applied Drama · Gamification · Simulation · assessment · lusory attitude · affinity space · practice · Role Distance · Magic Circle · Mantle of the Expert · Quest-to-learn · AMP (Autonomy, Mastery Purpose) · complex systems · relativity

> Truth is lived, not taught.—The Glass Bead Game
> (Hesse 1943)

Introduction

The commercial game industry has grown enormously, alongside increases in computing power over the last few decades (Cross 2011). By a variety of metrics it now surpasses the movie industry. Where at first games might have been developed from successful movies, now the reverse commonly occurs (Tomb Raider, Final Fantasy…). The development cost of games for game consoles, such as the Sony Playstation, which have traditionally captured a large slice of the market, has also

T. Bossomaier (✉)
Charles Sturt University, Bathurst, Australia
e-mail: tbossomaier@csu.edu.au

© Springer Science+Business Media Dordrecht 2015
T. Lowrie, R. Jorgensen (Zevenbergen) (eds.), *Digital Games and Mathematics Learning,* Mathematics Education in the Digital Era 4, DOI 10.1007/978-94-017-9517-3_11

risen. A top, so-called AAA title can cost upwards of $20 million to produce, with aggregate teams of 100 people or more. In September 2013, Grand Theft Auto 5 was launched. It was the most expensive game ever, at £170 million. But in the first day of sales, it set another record, boasting *£0.5 billion* in its first day, higher than any movie or game in history.

Serious games attempt to harness this massive interest in games for entertainment, for educational or training purposes. We shall look at the various objectives and the evidence, if any, of how well serious games go towards achieving them. Writing a textbook, particularly if it gets syndicated in the US, can be very lucrative. But such a book will be the work of one, or just a few people, with maybe some secretarial or graphics support. On the other hand, supplying a serious game to the same market has a gigantic upfront cost if the design and production quality are to meet the same standards seen in the entertainment world.

Cost limitations have meant many games for educational and training purposes have been feeble imitations of their entertainment equivalents. But this dire situation may be changing. The mobile game market has exploded alongside the rapid growth in smartphone technology. The smaller screen, reduced processing power and simpler interface (no joysticks, elaborate controllers) mean that game design has to assume a larger part of the overall budget, which, in turn, can be quite a lot smaller. In the film industry over the last decade we have seen movies, such as *Blair Witch Project* and *Saw*, made on miniscule budgets, go on to achieve major box office success. Here a novel idea transcended the massive movie budgets of traditional blockbusters.

The Economist argues that education has much to learn from games (Laibson 2013) and, in June 2013, reports that technology is really starting to deliver major outcomes in education, and large sums of money are changing hands. Major academic publisher Pearson has spent $880 million in technological acquisitions since 2011, while News Corp spent $340 million on acquiring Wireless Generation for its Amplify education arm (Economist-Anonymous 2013). Meanwhile Apple sold 3 million iPads for educational use in 2012. GSV Advisors (Global Silicon Valley Advisors) claimed educational technology investment reached $1.1 billion in 2012.

This chapter asks whether serious games work in delivering education and training and in supporting learning, and whether they are effective in their use of time and, by implication, whether they are cost effective. The approach here is very general and we spend some time at the beginning looking at the variety of games genres and opportunities that they offer. As Hickey and Zuiker (2012) point out, some national assessment exercises may impede deep learning. Our goal here, then, is to look at a bigger picture than national curricula and achievement targets. In the realm of school education alone, we have gamification to make repetitive, simple tasks doable on the one hand and, on the other, entire school programs built around such games, such as Katie Salen's Quest2Learn (Q2L) initiative.

At first there seems to be a paucity of thorough scientific studies with suitable controls. In a recent review, Hays (2005) from the Naval Air Warfare Center in Florida, asserts that "The empirical research on the instructional effectiveness of games is fragmented, filled with ill defined terms, and plagued with methodological flaws". But there are subtleties missed by too narrow a focus on very specific outcomes. In their profound and influential book *Rules of Play*, Salen and Zimmerman (2004) develop three aspects of games: rules, play and culture. These three categories turn out to be a useful lens for effectiveness and how to measure it. We shall discuss in more detail how the **rules** define sets of procedures and are in some sense *closed*, such as learning the laws of physics or mathematics. **Play** is more divergent, embodying broader issues of interests and identity. **Culture** takes us beyond the educational goals to the broader context of what the knowledge is for, why it is useful and its integration with the rest of life.

To these categories we will add a fourth, which has only recently achieved prominence. Since it arises from action video games, which frequently have a military context, we shall coin the phrase *collateral learning*. Unlike the collateral damage sustained in military action, collateral learning is an expected beneficial side effect of such games. Thus the prevailing view is shifting, from one where little Freddie is wasting away his youth playing video games, to one where Freddie is acquiring skills that will help him get his future dream job as a consultant radiologist.

As we move across these categories, the validation requirements and methodologies shift. They also extend into the broader issues of lifelong preparation through mathematics training (Clements and Samara 2011) and the risk to emotional development of poor educational practices (Shonkoff 2011). This broader, life-long picture necessitates the wide-ranging perspective of this chapter. The structure is as follows:

- We examine a broader context of games and simulation and how they integrate with the study of their domain. Computer simulation has been of enormous benefit to teaching, especially in the STEM disciplines, but it is intrinsically passive. Games involve agency, thus fostering *active* learning. The best game may go beyond the game to foster additional study of their domain, something we call *practising* to play.
- We discuss genres and dimensions of serious games along the lines discussed above, starting with highly focused maths games and zooming out to games in society. Beyond developing core skills in the early days of school, the student needs some understanding of what, to paraphrase Thomas Nagel, it's like to be a bat, a mathematician or a physicist (Nagel 1974). This idea takes us from homework problems in statistics, to assessing risk in lifelike situations, to the *mantle of the expert* (Heathcote and Bolton 1995).
- We look at the new fast-growing area of gamification. The evidence is that this is building a wave in education, training and the corporate world. But its merit within a deep learning framework is questionable in light of research on motivation.
- Serious games, of course, have to embody assessment and here we find a curate's egg: on the one hand, we have unprecedented opportunity for cost-effective adaptive learning, using online computer games and big data; and, on the other, politically charged issues of summative versus formative assessment.
- We conclude with the future outlook for serious games.

Games in Context

> I had tasted the bait and knew that there was nothing more attractive and more subtle on earth than the Game. I had also observed fairly early that this enchanting Game demanded more than naive amateur players, that it took total possession of the man who had succumbed to its magic.—The Glass Bead Game

Surprising though it may seem, the definition of a game has generated a lot of discussion, from Huizinga's Homo Ludens (1986) to Suits' Grasshopper dialogues (Suits and Hurka 2005) even before the computer game revolution. We touch on the definition of a game below, but a more detailed discussion is outside the scope of this chapter.

In this section we just want to put the idea of game into some context. The first issue is the distinction between simulation and games. The second issue is what we will call *meta-game* activity, activity beyond the game, but directed towards improving gameplay mentioned below.

Games versus Simulation

Three terms in common use—play, games and simulation—have attracted a lot of discussion since they overlap but are not identical. When we consider serious games, a further complication arises because the player has a learning objective outside the game.

Games frequently involve simulation of some sort of virtual world, but there are numerous discussions of simulation and games. The boundary is at times blurred. Our concern in this chapter is specifically with games, so we need to clarify the difference and put simulation to one side.

The ideas of play and games go way back in history, with eighteenth-century writer Friedrich Schiller[1], stressing the essential element of play to being human (Schiller 1794):

> der Mensch spielt nur, wo er in voller Bedeutung des Worts Mensch ist, und er ist nur da ganz Mensch, wo er spielt (to be fully human is to play)—*Friedrich Schiller, Über die ästhetische Erziehung des Menschen, in einer Reihe von Briefen, 15th Brief*

But one of the earliest and most influential writers on games was Johan Huizinga, born in the late nineteenth century. His influential book, *Homo Ludens* (Huizinga 1986) is still in print today! He looks at play in different domains, art, war, poetry and others, and popularised the celebrated term *The Magic Circle*, but the idea goes far back in history, at least to the Indian epic, the Mahabharata. A prominent theme therein is a game of dice, but this is played in a special, carefully laid out circle. The players are not allowed to leave the circle until the game is complete (Huizinga 1986). (Note, however, some complications discussed below).

[1] Widely known through his words used by Beethoven in his 9th symphony, which provided the music for the European Anthem.

The central concept of Huizinga's book is play, but games appear strongly too. In fact, he sketches out the framework for defining a game, given by McGonigal (2011), which we discuss below. Another influential book, Bernard Suits' *Grasshopper: Games, Life and Utopia* (1990), takes inspiration from the Aesop fable of the ant and the grasshopper. The ant works all summer and survives the winter. The grasshopper plays and dies. The book is a sort of Socratic dialogue between the grasshopper and his acolytes.

Suits' definition is neat, maybe a little unexpected:

> …To play a game is to engage in activity directed towards bringing about a specific state of affairs, using only means permitted by rules, where the rules prohibit more efficient in favour of less efficient means, and where such rules are accepted just because they make possible such activity.

This acceptance of the rules of game, Suits describes as the *Lusory Attitude* and goes on to put games central to the ideal of existence, a somewhat similar position to Hermann Hesse's Glass Bead Game (1943).

Jane McGonigal (2011) offers four defining characteristics of a game, in part derived from work by Suits (1990) and Salen and Zimmerman (2004):

1. **Goals** are essential and are one clear differentiation from simulation. Thus we might have a computer simulation of the effect of greenhouse gases on climate change. We could *play* with parameters and look at, say the effect of rising sea levels, bleaching of coral reefs or increasingly violent weather. But for our purposes this would *not* be a game. It could easily be made a game by creating goals, such as keeping the sea out of Sydney.
2. **Rules** define games from the earliest board examples, Chess 1500 years ago, and Go perhaps at least 3000. For a game to become widely played over time, the rules have to be reasonably constant. For these ancient board games, only occasional changes to the rules have occurred throughout their long history.
3. **Feedback** is a sophisticated feature of many computer games, with a variety of rewards and penalties as skill within the game develops. From an educational perspective, ongoing feedback as the game progresses, as opposed to a simple win/lose is desirable. We come to the idea of *stealth assessment* (Shute 2011) below.
4. **Voluntary participation** is subtle, since some people may be obligated to play a game, such as soldiers in a military war game. The idea here is that everybody accepts the rules and the game for what it is. An important corollary of voluntary participation is that the game should not be harmful, an issue we touch on in discussing applied drama below.

Unlike simulations, the goals of computer games usually have a carefully graduated series of levels, usually more sophisticated than a simple point system. The Nintendo Brain Training Workshop uses graphics of walking, cycling, driving, trains, planes and rockets to illustrate increasing levels of attainment. This *levelling up* is a key part of the engrossing and enduring nature of games and a building block of *gamification*. Klabbers (2009) has written extensively on simulation and games and their differences. He makes the distinction between design sciences (games) and analytical sciences (more tending towards simulation). Design sciences are holistic and have different means of evaluation—in the way one appreciates a picture in its entirety rather than, or as well as, the quality of individual brush strokes. This may hold for the evaluation of a game or simulation, but in the serious games domain we need to evaluate along a third dimension. This third dimension stretches from practice to context.

Klabbers (2009) and Salen and Zimmerman (2004) make much of complex systems theory in games. Complex systems are those for which no simple rules predict how they behave in any given circumstances. The simplest, well-known complex systems are exemplified in John Conway's Game of Life (Gardner 1970). Using very simple rules on a 2D grid, it generates bewildering patterns of behaviour, creating higher level dynamics structures of diverse kinds.

Complexity in a game ensures a richness and longevity, and encourages creativity and analytical depth. This may not always be required for a serious game, where a direct relationship between problem and learning outcome might be essential. But there are exciting opportunities for training in the handling of real-life complex systems, such as crisis management, international politics, long-term strategic planning and so on. The issue of meaningful assessment arises again in the Assessment Section.

Practising to Play

There is a somewhat complementary aspect to using games to teach and learn directly. Players of highly competitive cognitive games—Bridge, Chess, Go—actually spend a lot of time *away from the game*, studying and practising specific elements, just as, say, a tennis player may spend hours practising her backhand; Chess players spend hours studying openings; Bridge players spend hours studying bidding systems, conventions and play techniques. In the computer games world, first-person shooter enthusiasts will spend hours perfecting the use of some weapon.

Closely allied to practise for the game, are affinity spaces (Gee 2003, 2005) and fan culture (Jenkins 2006) (below). Thus perhaps we should envisage a second tier of serious gaming, *the motivation to study to be good at the game*, what we shall call the *meta-game*. In Relativistic Asteroids (Carr and Bossomaier 2011), discussed further below, players gain an intuitive understanding of relativistic dynamics to be able to respond fast and fluently away from the Newtonian world. They need to take into account time dilation, length contraction and mass increase to shoot asteroids and avoid being destroyed. This intuitive understanding is a foundational requirement for more formal knowledge. We live in a mostly Newtonian world (i.e., relativistic effects are not normally apparent) and so the understanding of Newtonian dynamics is something with which we grow up. Games can make comprehensible non-intuitive domains, of which we have no direct experience, such as relativity and quantum mechanics below. The rewards in the game are tightly integrated with relativistic skill, an issue which will crop up repeatedly.

But just as being able to hit a spinning cricket ball, a difficult computation even today does not allow us to write down and manipulate the equations for the Coriolis force. Thus second-generation, asteroid-type games need to integrate the physics and mathematics. The excitement and challenge of the game should encourage deeper study. So, in a relativistic space game, there might be advanced levels which enable the player to design a weapon. But to do so would require being able to solve relativistic equations and calculate their implications on a computer. This *meta-game* experience becomes more and more significant as we proceed through the four categories, which frame this article.

The game/meta-game issues present difficulties for classroom use. McFarlane et al. (2002, p. 205) in the TEEM report on educational use of computers presented results from a range of schools in the UK, obtaining 700 responses. Big successes of the games were in team work and communication. From a real-world, after school education, these are undoubtedly important skills. Yet teachers expressed reservations about the games taking up classroom time away from the core syllabus (from which these social outcomes were excluded).

There are two ways to deal with this criticism: one is to focus more and more tightly on the curriculum outcomes, as in Asteroids and Supercharged discussed below, but with some reservations on assessment agendas. The other is to embrace some of the philosophy of Ken Robinson, described in *The Element* (2009), and move towards a more flexible concept of educational outcomes, a debate outside the scope of this chapter:

> One of the essential problems for education is that most countries subject their schools to the fast-food model of quality assurance when they should be adopting the Michelin model instead. The future for education is not in standardizing but in customizing; not in promoting groupthink and deindividuation but in cultivating the real depth and dynamism of human abilities of every sort.

Dimensions and Genres of Serious Games

> If only there were a dogma to believe in. Everything is contradictory, everything tangential; there are no certainties anywhere. Everything can be interpreted one way and then again interpreted in the opposite sense.—The Glass Bead Game

This section considers the types of serious games, following along the lines of Salen and Zimmerman (2004), examining them through the ever-widening lens angle above: the sandbox; affinity spaces; culture; and collateral learning. An increasing amount of effort is going into the building of serious games, with multiple conferences being held annually and numerous studies of use in schools and elsewhere. Novelty alone is likely to generate improvements and the numerous tricks of game design are going to hold attention and create involvement. Thus it requires very careful work to entangle these effects from improved learning in a given timeframe. In a recent meta-study, Girard et al. (2013) found that, although there were numerous studies, they rarely had control groups. Thus the outcomes were not as forceful as one would hope. There are *definitely positive* results, but the overall picture is somewhat murky. In general, we are likely to find differences between goals and genres, so we shall consider several areas in the following sections.

Building Sandcastles

Computer scientists have adopted the idea of a sandbox as a place to play, using the metaphor of sand not getting out, to safely experiment with new ideas. The first kind of serious game is essentially played in a sandbox—it ignores broader social or cultural issues and is not even particularly focused on other gamers. Such games, of which there are many, teach skills, ideas or theories. Many maths games, discussed elsewhere in this volume, fall into this category. Games which teach manual skills, from car mechanics to surgery are effective and very easy to assess.

Closely linked to games that develop technical skill are games for the quantitative STEM (Science, Technology, Engineering, Maths) disciplines. The interest in games for teaching them arises in part from an awareness of declining performance in schools in this domain—worse in 1986 than in 1970, with little improvement through the 1990s and 2000s (Echeverri and Sadler 2011).

Flight Simulators and 3D Skill Training

Long before Pong, arguably the first video game, appeared in 1972, flight simulators were already in widespread use. Real cockpits, built into huge moveable containers, became the norm for pilot training. Flight simulators have been part of the computer games genre for a long time and have gotten steadily better and more realistic as computer power has increased.

Such major simulators now exist in all sorts of domains: trains; cranes and port machinery; mines and mine rescue. Computer games are taking over more and more of the roles of physical simulators, being much lower cost, more flexible and, of course, easier to replicate. Thus there is not much argument that these simulators work. In a strange twist of life imitating art, military drones now use game-like interfaces with actual game consoles to control real aircraft operating thousands of miles away, sometimes with deadly effect. 3D skill acquisition through games now extends into surgery, car mechanics and other applications pop up with increasing frequency. But there is one possible problem with serious games for domains, where errors may have serious consequences, such as medicine. The problem is stress. The real situation may be very much more stressful than the game and stress may lead to distorted perceptions (Lupien et al. 2007) and consequent errors.

Intuition Beyond Our Senses

The early days of physics addressed things we could experience directly, the movement of objects under the action of forces, the transformation of the states of matter, from solid to liquid to gas, things for which we have sensory knowledge. As physics and chemistry developed, their theoretical framework became less and less immediately accessible.

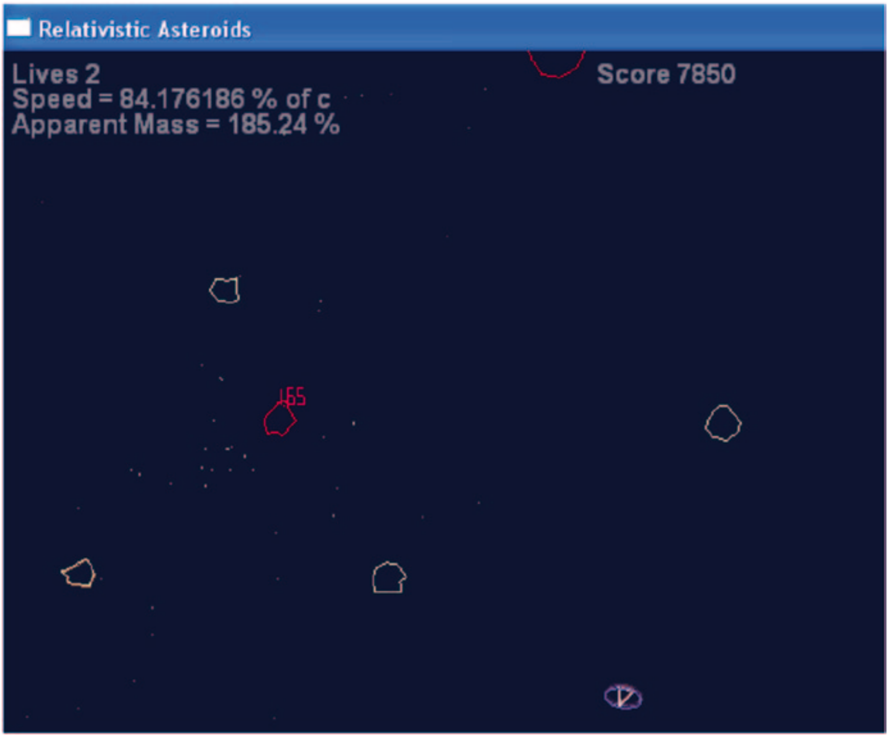


Fig. 1 Relativistic Asteroids (Reprinted from Australasian Journal of Educational Technology)

One of the greatest innovations in physics, Einstein's theory of relativity, brought with it numerous counterintuitive ideas, contrary to everyday experience. By adopting the stance that the speed of light was constant in all inertial reference frames, the increase of mass with speed, the slowing down of time and length contraction followed naturally. But these dynamics are so different from Newtonian mechanics that the equations which describe them have no physical intuition to substantiate them.

In Australia in 2013, special relativity is now part of the school science syllabus. Visualisation and games are powerful tools to make it accessible to school children. Carr and Bossomaier (2011) developed a computer game based around the early computer game of asteroids (Fig. 1). Like Pong and Tetris, these old games are still fun to play. But in relativistic asteroids, asteroids and ships move at close to light speed and therefore move differently on the screen. At close to light speed they change shape, according to the Lorentz contraction. Aiming at an asteroid is different to a normal asteroids game and a time bomb feature introduced the idea of time dilation. This game successfully created a sense of how things moved under relativistic physics. The equations become embedded in practical experience of how things behave close to the speed of light.

However, like the maths examples, actually manipulating the equations is not part of the game, and transferring such manipulations to exciting gameplay remains a challenge. Some of the games in this domain reflect their low-budget origins. But poor eye candy does not substitute for poor design. Some such games are weak because the gameplay is completely decoupled from the learning objective. For example, one might have a series of arithmetic problems and a reward for success being to throw a custard pie at a politician. Fun though this may be it is at best a weak motivator to do some maths exercises. It feels more like the category of gamification (below). This author is of the very strong view that gamification plays no role in school or higher education, since it mitigates the development of interest and intrinsic motivation.

In Supercharged, another space metaphor is used, again, to teach physics intuition. A spaceship's motion is affected by its charge and charge of surrounding objects (Squire et al. 2004; Squire 2006, 2008). Experiments were conducted in a US 8th-grade class comprising a total of 96 students. Both boys and girls improved relative to control groups. Post-session interviews revealed better qualitative understanding of the behaviour of charge and fields, but did not achieve a full understanding across the cohort.

Thus the exercise was a success. It also revealed the problem hinted at the beginning of the chapter. Many kids play commercial computer games and they bring the standards of these highly refined games to educational games. It also transpired that teachers remained essential to encourage reflection on the outcomes of the game and to take learning to a deeper level, another aspect of the meta-game experience.

Exogenous, Endogenous Games and Flow

Not all educational games seem to this author to be particularly good designs because their reward mechanisms are flawed. A number of games exist, for example, for basic accountancy. In the simple Trebuchet game, answering multiple-choice questions in accountancy allows the player to build a catapult (trebuchet) to launch the teacher into orbit. In an American football game (Financial-Football 2013), the graphics are much more sophisticated than in Trebuchet, with 3D representation of the players on the field and sound effects from the play and the crowd. But, the game dynamics are dreadful. Progress up the field is governed by answering accountancy questions. In short, such games decouple the training element from the gameplay. Rieber (1996) describes such games as *exogenous* and they could be considered simple examples of gamification.

We can do better according to Squire (2006). All the games developed therein are *endogenous*, that is, they use gameplay which is intrinsic to the training element (e.g., making financial decisions in the game). The nature of rewards crops up again when we consider gamification.

The best games achieve high player motivation and can result in what Csíkszentmihályi (1990) called *flow*, a state of intense concentration and lack of awareness of outside stimuli. Flow usually requires a careful matching of skill to difficulty level—there must be continual incremental challenge without it appearing insurmountable. Video games are often successful at achieving flow (Holt 2000; Chen 2007). In serious games, stealth assessment, discussed below, has been used to keep the player in a flow through this careful matching of difficulty to skill level (Shute 2011).

Mathematics Games in Schools

As Girard et al. (2013) note, there are a few good studies of the effectiveness of serious games, but there are few in the mathematics domain. The overall outcome is fairly positive, both in terms of engagement and achievement.

Kebritchi et al. (2010) performed a meta-study of 16 papers using computer games for maths teaching. Most outcomes were positive, although the methodologies were varied and often did not include control groups. They then carried out a study with 193 students using a game DimensionM for teaching algebra. 171 students used the game, while 76 students formed the control group. The outcomes were significant, but the effect on motivation as measured was weak.

Lindström et al. (2011) carried out a study in Sweden with children aged from 8 to 10, to help them learn the base-10 number system. The games they used featured not only numerical challenges but also two other pedagogical features: collaborative learning and learning by teaching (similar in some ways to learning by design). The games featured a teachable agent, which the players could train to play the game. Teaching the agent, plus playing against somebody else, lead to successful collaborative learning.

Ke (2013) studied the use of games for teaching mathematics in high school in two different school environments, an urban school and a rural pueblo school for Native Americans. Both studies had a strong qualitative component, seeking attitudes towards game-based tuition. The results, as measured by state examinations, were marginal for the rural school and non-existent for the urban school. The study did not have any sort of control group for comparison.

Ke (2014) then went on to study the use of *designing games* as a learning tool, which he sets in a broader educational framework of *designing to learn*. The idea here is a powerful one: the process of designing a learning tool to teach other people is an excellent use of increasing one's own understanding. The results were positive, albeit, again without a control group.

Castro et al. (2014) developed a range of games to help children with Dyscalculia (mathematical learning disabilities). With such children, there is not only the challenge of finding ways to help them learn, but also the challenge of developing motivation. Success generates enthusiasm, seemingly insurmountable difficulties rarely do. A family of a dozen or so games was created, each targeting a component of elementary maths.

This was a strong study, beginning with an initial cohort of 300 children aged 7–10, from which 26 children with Dyscalculia were selected after a pre-test and consultation with teachers. They were divided into experimental and control groups, the experimental group showing greater improvement in the post-test over the control group. It was also significant that the children enjoyed playing the games, even asking for more time to continue playing.

Most applications of serious games in mathematics have focused on these early years. As we move to senior grades and university level, tools such as Mathematics™, Matlab™ and Maple™ have made teaching higher maths much easier, through visualisation and facilitation of algebra. There are plenty of opportunities for serious games and, perhaps especially, learning by design in this tertiary space.

Play: Fuzzy Edges to the Magic Circle

When we talk about playing Chess, creativity and exploration are an intrinsic part of the game. In this section, we want to move beyond creativity within the game, within the magic circle, to the extensive divergent activity that goes on about the game. Henry Jenkins promoted the idea of fan culture (Jenkins 2006), exploring popular genres across television, film and games. Fans contribute huge amounts of discussion about the content and their personal reactions to it.

Since Jenkins began his seminal work on fans, the domain of supporting material, mostly on the web, has exploded. Gee (2005) coined the term *affinity spaces* for this external structure of games, with a special interest in serious games. Gee wants to distinguish between a community (which requires all sorts of definitions of membership, etc.) and a space where people interact over some shared interest. The issue of community or communities is moot. There may be antagonism and fractures within such a space.

Players discuss many different aspects of game and gameplay, but also use the affinity space to help with the design of new levels. This leads to the idea of *User-Generated Content*, now a study area in its own right (Lastowka 2013), redolent of the learning by design adopted by Ke (2014) for maths games. Adding extensions to games goes back a long way, with Quakebut now spread to extension systems which require no programming skill. One such example is Little Big Planet, and its affinity space Little Big Planet Central. It now advertises 8 million user-generated levels (Central LBP 2013).

Culture

> The Glass Bead Game is thus a mode of playing with the total contents and values of our culture … is capable of reproducing in the Game the entire intellectual content of the universe. —The Glass Bead Game

The fan culture around games extends the game to discussion of its rules, strategy, design, experience and all the things gamers talk about. But the great games go further and impact culture itself. It has always been so, from rites of passage to the ancient board games.

Applied Drama

Serious games are sometimes referred to as *epistemic games* (Shaffer 2004, 2006), which focus on the player's experience and identity within a real-world setting. Closely related to this is the body of work by Heathcote (1991); Heathcote and Bolton (1995); and Heathcote (2002) on *mantle of the expert.* These frameworks drive *Applied Drama*, a training methodology used in Communication and domains such as Public Relations (Carroll et al. 2006). It comprises playing out of scenarios under the supervision of a *Drama Master.* But unlike an ordinary thespian activity it has several distinct features:

- *The players are the audience.* They play a role but watch their role in its interaction with others.
- The idea of *role distance* (Carroll and Cameron 2005) is crucial.
- The Drama Master *dynamically controls the unfolding of the scenario*.

Dramatic enactments are not as harmless as they may seem! Some, maybe many, people cannot partition emotionally charged mindsets, such as trust, into a game environment and the real-world. Unless properly designed and supervised, a betrayal *within* the enactment becomes emotionally damaging *outside* the game. To avoid this role, distance, where people avoid real-life emotional involvement in the drama, is essential. The Drama Master achieves it through being able to stop the enactment at any point, encourage feedback and discussion and then resume the scenario, perhaps where it left off or at some other point dependent upon the discussion. This *in-role, out-role* dynamic minimises the risk of emotional harm.

To bring applied drama into the online world, a game engine, CADGE, was developed to deliver applied drama online, in the first instance to train people in crisis communication (Coombs 2007; Heath and Millar 2004). As recent major disasters, such as Hurricane Katrina or the BP oil spill in the Gulf of Mexico, have convincingly demonstrated, communication is a crucial element of successful crisis management. Apart from the dissemination of information rapidly and effectively, without overload, it has to deal with numerous, often conflicting stakeholder concerns. Organisations may be economical with the truth in order to minimise legal liability, perhaps at the cost of rapid resolution or containment.

CADGE is built around the notion of media resources, such as film clips, specially constructed or taken from real news footage. A large set of these forms a core part of the game; their selection is dynamic, being dependent upon the direction the scenario takes. They are the sort of media feeds which might come through during a crisis, such as a flood, and allow the generation of media artefacts in response. Players represent various stakeholders, government, journalists and corporations, and have to assume the *mantle of the expert* (Heathcote and Bolton 1995) appropriate to these roles.

As noted above, developing AAA computer games is expensive. Thus a key design element was a *Domain-Specific Language* CRASL, with which a domain expert, as opposed to computer expert, could construct a new scenario to run within the game engine. This generalisability is an important cost issue for serious games since it amortises the development cost over multiple games.

Evaluation with undergraduate students in Communication showed the game to give a real meta-game experience, with focus group comments such as:

> It was difficult for me to know exactly what angle to take and what information to include or leave out. At one point I had five paragraphs jotted down, all able to be the lead para in a story. I assume that is what separates the good journalists from the great ones. The great ones have the ability to attain the vital information the fastest and compile a relevant news story in a short amount of time. For me this is still difficult…

and

> The flood simulation highlighted the role of different media forms in communicating all the relevant information. The exercise was intense, stressful but beneficial in that it encouraged a more interactive approach to accessing information. It helped in getting the information more quickly and efficiently, which is always welcome in the face of deadlines and the competitive pressures of the job.

The evaluation of learning in a social communication domain such as this is fraught with difficulties. The assessment is inevitably somewhat subjective, thus creating suitable control groups is difficult. So far, we know that motivation is enhanced and the *mantle of the expert* projected, but the degree of learning is an area for future research.

The future looks good, however. The integration of applied drama with real computer simulations of a crisis unfolding in real-time provides feedback of how effective decisions taken actually were. So, running the enactment, without drama master intervention, can measure learning. Then as with the Go studies, it is possible to titrate decisions taken against best practice, or the most successful players and teams in a given scenario.

Creating new scenarios, using a tool such as CRASL or other authoring mechanism, allows learning by design, already known to be effective elsewhere (Ke 2014).

Collateral Learning

Our thinking so far has been around designing a game to teach some field of knowledge. But there is an entire cottage industry in games designed to have a direct effect, either on the mental state of the player or on their cognitive or perceptual skills. Bio-feedback games, such as Bio-Ball, and a family of similar games, use muscle *relaxation* to control a ball (NASA 1997). There is not much evidence that such games actually work as intended, so we will devote little attention to them here.

More recently, there has been numerous brain training games, such as Nintendo's Brain Training Workshop. Many of these are only loosely based on neuroscientific data, but there have been some significant advances, as we now discuss.

Learning How to Learn

Research in expertise over the last half-century emphasises how specific expertise is to a domain. Top Chess players have to start all over again to become top Go

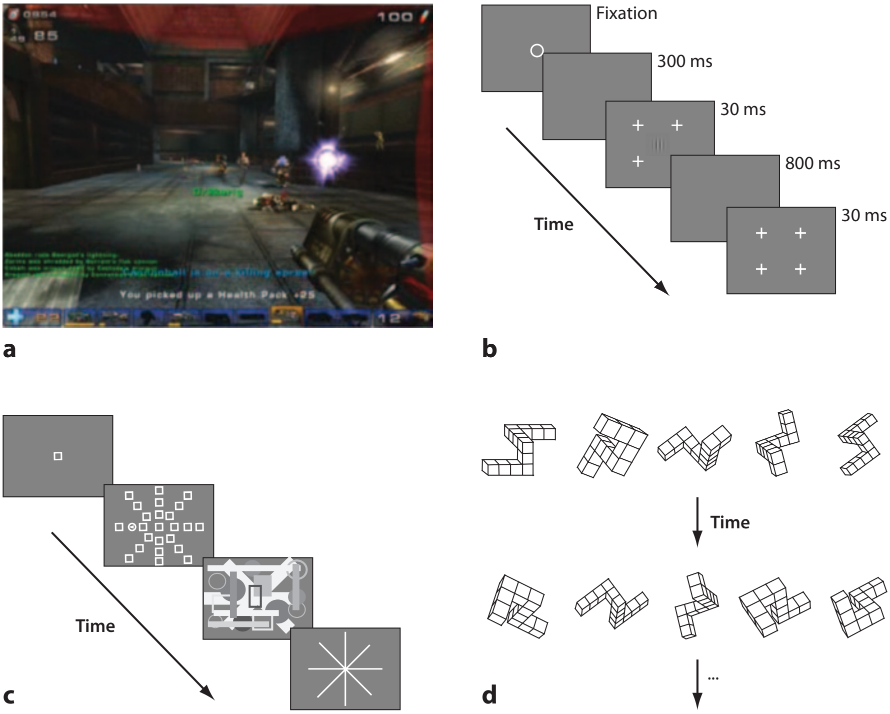


Fig. 2 Training on action computer games as at the top left, creates improvements in visual search, mental rotation and contrast detection (Reprinted from Bavelier et al. (2012) with permission) (see text)

players. Expertise does not transfer because it relies on the accumulation of a very large number of patterns over time (Gobet and Simon 2000; Simon 1959; Groot and Gobet 1996). Thus it was surprising and very interesting to find that some of the skills acquired in computer games *are* transferable.

Bavelier et al. (2012) review a range of studies showing how basic perceptual skills improve and *show long-lasting effects in other non-game tests*. Figures 2 and 3 show three tasks which players of video games perform better than control subjects:

Mental Rotation: is commonly found in intelligence tests

Visual Search: looking for things in crowded environments

Contrast Detection: seeing a faint object in the background

The panel at the side of Fig. 3 shows how performance on these tasks holds up months afterwards. As one might anticipate for improvements in perceptual processing, the games used here were fast action games.

This collateral gain is no barrier to developing games specifically for brain training. Two examples stand out. They are important because, although designed for

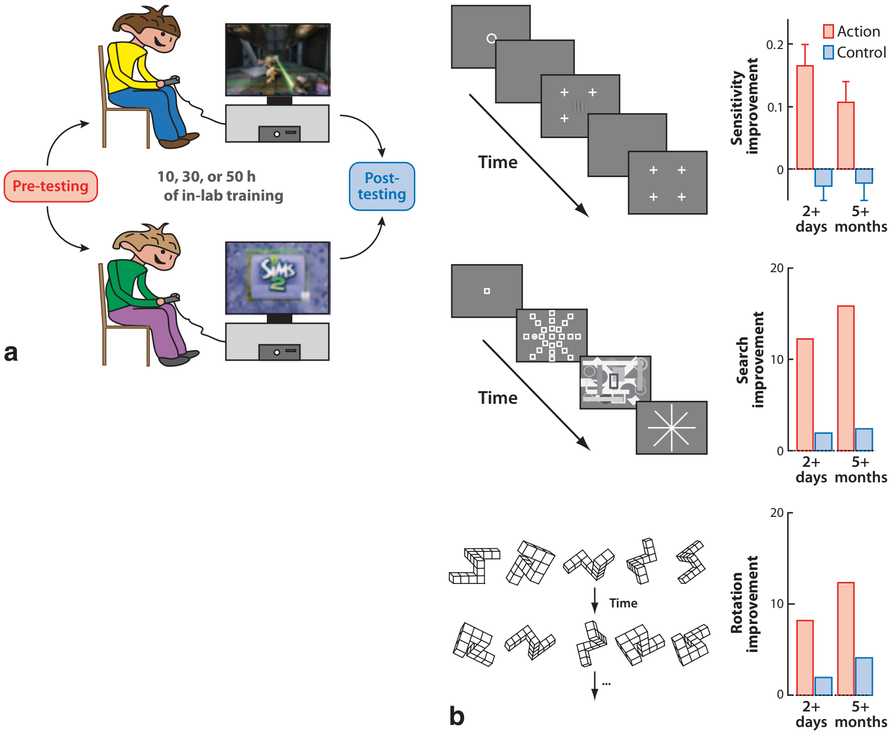


Fig. 3 Longevity of improvements in search, contrast detection and mental rotation obtained with video game training

cognitive training, they have demonstrated generalisation to domains outside the game.

Jaeggi et al. (2008) made quite a stir when they showed that a simple video game could improve working memory[2]. This was surprising because the prevailing view was that working memory was something set very early in life, which deteriorated gradually with age. Even more surprising that the gains in working memory on the game tasks generalised to other working memory tasks and, in particular, led to an increase in general intelligence (as measured by IQ-like tests).

Strobach et al. (2012) show that action games also enhance multitasking and now, at the time of writing in mid-2014, another study on brain plasticity has appeared, this time showing gains for people aged 60 and older. Anguera et al. (2013) developed a game, Neuroracer, which is a driving game with added distractors. The players have to respond as quickly as possible to the distractors without going off the road. A few hours per week show dramatic gains in working memory and multitasking, which transfer to other domains and persist for at least 6 months afterwards.

[2] Working memory is closely related to short-term memory. It is essentially the things you hold in your mind at one time for analysis and manipulation.

Unlike many other studies, which have made claims for brain training sometimes not standing up to intense scrutiny, Anguera et al. (2013) back up their behavioural results with comprehensive brain imaging and a coherent neuroscientific model.

This fascinating area is still rapidly developing. Although the gains are clear in the work so far, there is another recent result, which suggests that design details may be critical. This was not a game study, but a test of the capacity for multitasking. Almost all folklore and a lot of experimentation conforms to the *practice makes perfect* dictum. Not so for multitasking! Ophir et al. (2009) showed that chronic multitaskers, people reading social media, answering the phone, watching the screen, while pushing the cat off the keyboard, perform *worse* on tests of multitasking ability. Perhaps related to this is an earlier study by Koechlin and Hyafil (2007) which found that we can handle at most two independent tasks without interference.

We conclude this section with a note of caution. Exciting though all these results are, the experiments are very difficult. Sometimes subtle biases may occur, as suggested by Boot et al. (2008), weakening the results. But the overarching outlook is very encouraging.

Gamification

> All the tasks are in themselves small, but each one has to be carried out at its proper hour, and the day has far more tasks than hours. —The Glass Bead Game

Gaming, for non-entertainment purposes, pervades many new areas in the form of *gamification*. From a neat idea and a community website, *gamification.org*, Badgeville has now acquired the use of the term on major social media, notably Twitter, Facebook and YouTube (Perez 2012). A recent start-up, they have now raised $40 million in funding and have an international presence across many large companies.

Creating a game out of mundane things, cleaning the bathroom in the case of Jane McGonigal's household (McGonigal 2011), attempts to add motivation and excitement to chores which would otherwise not get done or get done less often or less thoroughly, than might be desirable.

Gamification is a rising phenomenon of some sort. The Gartner Group 2012 Hype Cycle (Pettey and van der Meulen 2012) has it on the rise, peaking in 5–10 years. At a simple level the meaning of the term is obvious—making non-game things into a game but, somewhat surprisingly, a lot of discussion has centred around the definition. Deterding et al. (2011) propose:

> the use of games design elements in non-game contexts

and this has become quite common. Houtari and Hamari (2012) go for a more specialist definition for service marketing:

> a process of enhancing a service with affordances for gameful experiences in order to support user's overall value creation.

Despite this very recent activity in finding a definition, the *game mechanisms* used boil down to just four things: points, badges, leader boards and levels—all pretty self-explanatory. But if we forget computer games, these motivators have been around for a long time. One might even argue that the Olympiads of Ancient Greece nearly 3000 years ago were a form of gamification: the prizes were made of olive leaves, but the agendas were large-scale politics.

Badges are a prominent feature of the Boy Scout and Girl Guide movements, which were formed over a century ago. Points and leader boards are featured in everything from amateur sport to sales force motivation. Levels appear frequently; learned societies, for example, run through various levels of members to fellowship; loyalty programs, from airlines to hotel chains, have different levels, with George Clooney reaching the 10 million mile club in the film *Up in the Air*.

So, what is new seems to comprise firstly the use of computer tools to add game elements to any activity with relative ease and, secondly, the rapid spread to so many domains which have not previously had the full gamut of game features. A 2011 Gartner report suggests gamification will spread widely through the commercial world, with 50% of organisations involved in innovation gamifying some of their processes by 2015. Brian Burke at Gartner (Gartner 2011) states that:

> Gamification describes the broad trend of employing game mechanics to non-game environments such as innovation, marketing, training, employee performance, health and social change. Enterprise architects, CIOs and IT planners must be aware of, and lead, the business trend of gamification, educate their business counterparts and collaborate in the evaluation of opportunities within the organization.

The Pew Research Center carried out an extensive survey of diverse experts on the future of gamification (Anderson and Rainie 2012). They formulated a series of tension pairs, two propositions with opposing outcomes in 2020. Around 1000 people participated, with an opt-in and therefore not random selection. An example of one such pair is *Gaming is double-edged: it can be fun, useful increasing engagement and personal improvement; it can also be manipulative, insidious*. The overall expectation was an ongoing increase to 2020, but with mixed feelings about how desirable and effective it would be, as hinted in the tension pair example. Some of the respondents hark back to the point made earlier: gamification is a new wrapper for techniques which have been around a long time viz.

> Gamification is an overblown term for old-school marketing. Yes it works, No, it's no game changer (pun intended). —Paul Jones (Anderson and Rainie 2012)

The idea of cognitive manipulation cropped up repeatedly with its good and bad connotations.

One of the four game elements above, the awarding of badges, has taken on a life of its own. Mozilla, which makes the popular Firefox browser, has introduced the Open Badges (Mozilla 2014), a comprehensive framework for creating badges which includes: the image; URLs which encode details of what the badge is for, how it is earned and how it is validated; and tools for maintaining collections, called knapsacks, of badges, displaying them and so on.

Badges are particularly effective at influencing user behaviour. Anderson et al. (2013) developed a model for how users respond to badges and find it predicts a *steering effect* and validate it against the popular website Stack Overflow. Essentially, users devote more and more time towards the badge the closer they get to it. This in turn shifts their distribution of activity. In the education context we will come to shortly, this steering effect has to be carefully balanced.

British company Hide & Seek, operates in a similar space of gamification of everyday things and collaborative/community engagement, i.e., the spin-off is the goal. Complementing the Olympics in London was the 2012 London Showtime Festival, which featured a huge range of community activities. Amongst them were 99 Tiny Games, across all the 33 London boroughs. Tiny Games was funded through Kickstarter (Kickstarter 2013), one of the first and biggest crowd-sourcing activities.

Of the many such applications springing up everywhere, we now want to look at the increasing activity in, and the relevance to, education and training. Of the variety of applications, we can distinguish two broad categories: increased participation and increased performance levels.

Perhaps because of the pervasiveness of online and multiplayer games, increased participation seems to be achievable through gamification. Fitz-Walter et al. (2011) developed *Orientation Passport* to engage new students in the variety of activities offered in orientation week and at the beginning of semester. Although it was moderately successful, it highlighted a freakonomics hazard (Levitt and Dubner 2005): so, if points were awarded for attending up to three events, students might attend just three.

College students also respond to gamification. At the US Air Force Academy, de Freitas and de Freitas (2013) developed a gamification tool, *Classroom Live*, to enhance participation, what they refer to as *classroom gamification.* Survey results after the first 3 months of use are generally positive.

Hakulinen et al. (2013) carried out a more quantitative study of students studying online data structures and algorithms, aspects of computer science. Badges were awarded for a range of good study practices, as well as performance *per se.* The sample size was 281, but only a small fraction showed behaviour change as a result of earning badges. But this highlights an important feature of the design. The badges were meant to be motivators in their own right. Getting badges had no impact on the final grades.

The need to divorce game rewards from course outcomes or requirements is stressed by Landers and Callan (2011). They examine the psychology of gamification using a series of tests in psychology courses embedded within a purpose-built social network site. The tests were for training only and were not included in any grade assessment. The participation was around 30 % of about 600 students. Likert tests (scale of 5) showed a strong bias of (high) scores of 3–5 on questions relating to fun, enjoyable and rewarding.

At the school level, classroom gamification gets a great deal of attention. Studies are too numerous to consider here, so we will consider just two examples: Mathland and Buzzmath. Both blend skill development with participation.

Franelli (Ross 2010) developed Mathland to enhance classroom maths teaching in Canton, near Detroit. Each student gets an avatar on a leader board which the whole class can see. As they progress through various proficiency tests their avatar moves up the board. Although each pupil tracks their own progress on the board, they can also see how others are doing. Although there is no control study, the class improvements were significant: 13 % increase in attendance in 2 years and 22 % increase in statewide assessment in 3 years.

Buzzmath (2014) makes use of the Mozilla Open Badges system discussed above, with badges for many different skills in basic numeracy. Developed by a multidisciplinary team of teachers and designers, it is a commercial product but is used in North American schools. Although controlled evaluation does not yet seem to be available, the engagement seems strong and support has been received from the prestigious MacArthur Foundation.

There are some issues with gamification, though, highlighted by Scott Nicholson of the *Because Play Matters* lab at Syracuse University (Nicholson 2012). The lowest level of gamification is simply a point collecting system, which well-known game polemicist, Ian Bogost, has attacked vociferously (Bogost 2008, 2011). Gamification needs to go beyond this to more meaningful play dynamics and can include mechanisms such as people setting their own goals. Deci (1971) argued that extrinsic rewards weaken internal motivation and extensive follow-up work reinforces these conclusions across many different domains of learning (Deci and Ryan 2008). But where intrinsic motivation is weak, gamification with external rewards, can still be a productive way of getting things done.

More recently, Grant (2011) at the Wharton Business School, summarised a wide range of studies, showing external motivation, such as financial incentives, leads at best to lower performance and at worst exaggeration and unethical practices. One prominent voice, cited therein is Daniel (Pink 2011), whose TED talk is highly recommended. He advocates the trilogy of *Autonomy, Mastery and Purpose* (AMP) as the key to superior performance.

So, where does this leave gamification? Pink (2011) makes the point that AMP is crucial to creative work, finding divergent and novel solutions, which are absolutely essential to the modern world. Gamification, though, still seems to have a place in dealing with concrete tasks, where novel solutions are not (one assumes) required and where intrinsic motivation is hard to find. It seems to have a strong role in remedial or school classes where motivation and/or attendance is low for whatever reason. Whether it belongs in tertiary education is a moot point, to which this author is in the negative camp.

But even for very young children, the best mathematical games or interventions, dig deep into research in the development of cognition. Two highly successful programs, Number Worlds and Building Blocks do precisely this with carefully constructed *learning trajectories: a goal; a developmental progression; and a set of instructional activities* (Clements and Samara 2011). Given the hive of activity in gamification of elementary numeracy, the concluding remarks by Clements and Samara (2011) are worth remembering, that we want to get deep into mathematics:

> There is much to gain, and little to lose, by engaging young children in mathematical experiences. Mathematics is cognitively foundational…. Evidence supports interventions that provide foundational and mathematical experiences in number, space, geometry, measurement, and the processes of mathematical thinking.

Assessment

With the increasing use of technology in schools, the amount of data available for analysis is vast. Companies such as Knewton specialise in the collection and analysis of such data, making it possible to adapt learning to each and every individual (Economist-Anonymous 2013). It also becomes possible to measure performance *in situ* as opposed to more conventional means, so-called *stealth assessment*.

Although games are played for fun, for and in themselves, players nevertheless like to keep league tables, master ranking systems, national trophies, the Olympics writ small from checkers to chess, from snap to bridge. These are the grist of gamification and obviously we would like to harvest such competitive data to serve as assessment.

Most serious games are oriented towards beginners, or players with not much more than minimal experience. But mastery takes a long time. The commonly accepted view, which originates with Nobel Laureate Herbert Simon, but has since been developed by people such as Fernand Gobet and Karl-Anders Ericsson, is that deep expertise takes time: 10,000 h of focused experience, or the acquisition of 200,000 pattern fragments or chunks.

That would be a lot of time spent playing a game, unless of course the game was an end in itself, such as becoming a grand master at Chess. But the glory of the great games of history, such as Chess and Go, is that beginners and masters play the same rules on the same board. This opens up the potential to assess players from the moves they make. It turns out not only to be possible to do this, but an unexpected finding pops out—tipping points in the acquisition of expertise. We elaborate on these findings and explore the implications for assessment generally later in the section.

Tipping Points in the Acquisition of Expertise

Archimedes' Eureka moment transmitted a word directly from ancient Greek to modern English. We have all had the experience of a sudden flash of insight. But it is also a common experience to see, often quite suddenly, how all the pieces of a domain of knowledge fit together. Until now it has been difficult to do little more than conjecture how this might work, or even how true it is. It is hardly feasible to do experiments lasting 10,000 h. But asking experts how things progressed for them is a notoriously unreliable methodology.

The advent of big data—very large volumes of data online—has enabled an entirely new method. We can now look at what people do, beginner or expert, over thousands of decisions, maybe millions of decisions in the near future.

Because game associations rank players, there is a ready-made metric to relate the decisions they make to their ability. The Game of Go is an ideal game to study. Firstly, it is the oldest game by far listed by Salen and Zimmerman (2004) in their game appendix and is very likely to be the oldest game with any strategic depth. Its complexity, but human tractable complexity, may be one reason it has lasted for 4000 years, with each generation finding new moves and strategies.

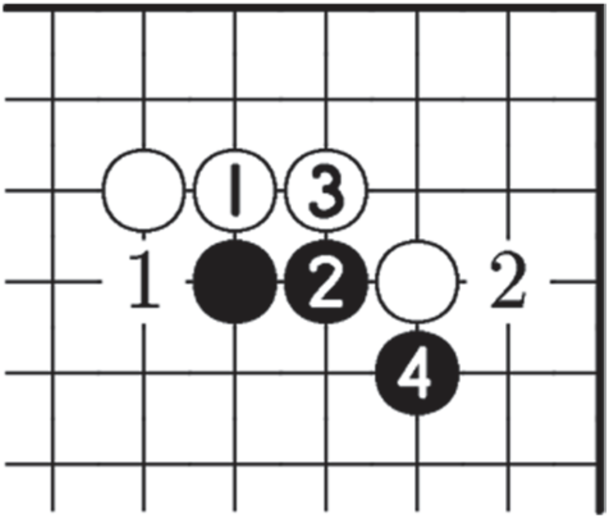


Fig. 4 A fragment of a Go board. If black plays at position 2, then the white stone has only one liberty (free grid point) left and will die if black is allowed to play there too. If white joins this stone up with the stone marked three the stone is safe (for the time being). If white can play at the point marked 1, then black needs to join 2 and 4. If white can occupy this point the two black stones will die

Go is interesting for a couple of other reasons. Firstly, it is extraordinarily simple. There are no pieces with different roles, as say the king, queen and knight in Chess. There are just black and white stones, as shown in Fig. 4. There is no complicated board, like Monopoly, just a simple 19×19 grid. It has just a couple of simple rules, from which emerges a game of great subtlety, a quintessential complex system. Lastly, it is still the most difficult of all games for computers. Go bots struggle to reach club level, lending the game an air of mystique as one of the few bastions of human intelligence not yet breached by computers.

Fortunately, there are lots of games recorded online, which means we can compare the move profiles of the top professionals (9-Dan Professional, denoted 9P, effectively equivalent to a Grand Master in Chess) with all the players below. Doing this generated three important findings:

1. It takes a long time before the big picture takes shape.
2. There is a tipping point on the way to 9P.
3. The tipping point occurs through changes at a very early perceptual level.

Salen and Zimmerman (2004) and Klabbers (2009) both stress the importance of complex systems in thinking about games and this notion of pieces self-assembling into larger structures is a canonical theoretical mechanism (Bossomaier and Green 2000). A profoundly important paper by Erdös and Rényi (1960) captures this idea in the notion of random graphs.

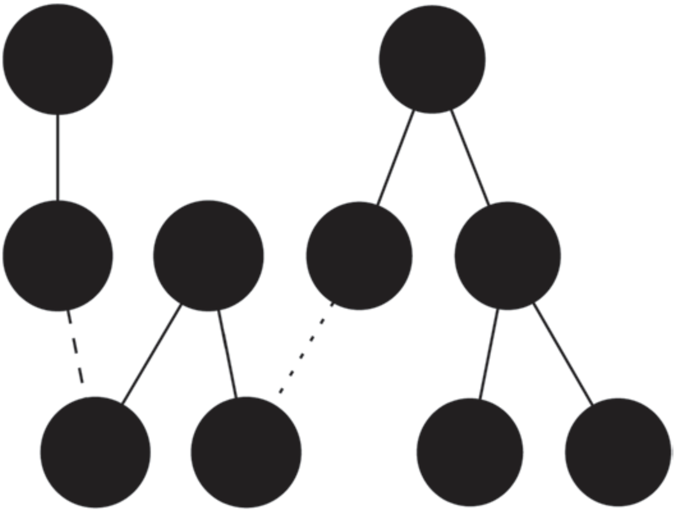


Fig. 5 Erdös Rényi random graph formation. When the dashed edge is added a second five node component is formed. Adding just one more edge, such as the dotted edge, makes the graph fully connected

Figure 5 shows the development of a random graph. We start with a collection of points (*nodes*) and draw lines (*links*) between them at random. As the number of links grows clusters start to appear. Then adding just one extra link can join clusters together, making a much bigger cluster, creating *giant components* and the graph becomes fully connected, where there is a path from every node to every other node. This process is referred to as the connectivity avalanche and is an example of a *phase transition.*

Seeing the Big Picture

It is a common experience, but one difficult to quantify, that we often learn things bottom up. Parts start to fit together and parts ultimately join up until global relationships are clear. The random graph model discussed above shows in a simple abstract way what is happening. When, and how does it occur though, is a largely open question.

For Go, Harré et al. (2011b) determined when the big picture appears. Figure 6 shows what happens. By analysing tens of thousands of decisions from games at different ranks, it was possible to compute how far a player was in strategy from a 9P (the best). The mathematical details are based around Shannon's ideas of Information Theory (Shannon 1948) which can be found in the original paper, but here we just want the qualitative idea. The key result as explained in Fig. 6 is that the global insight does not really develop at all until 1-Dan Amateur. This is a seriously good Go player. It would usually require several years of serious tournament play to get to this level.

The challenge and opportunity for serious games comes in being able to assess, *as people play*, when they reach this understanding of global factors. The challenge lies in that such games have to address the cohort of people well beyond the beginner level.

The Expertise Flashpoint

Turning now to the tipping point in expertise, the flashpoint where everything fits together. Again, we can find this from the analysis of online games. Figure 7 looks at how the strategies from some rank compare with the rank just below. The lower curve in the figure is the comparison with the best, 9P. It falls steadily as we saw in Fig. 6

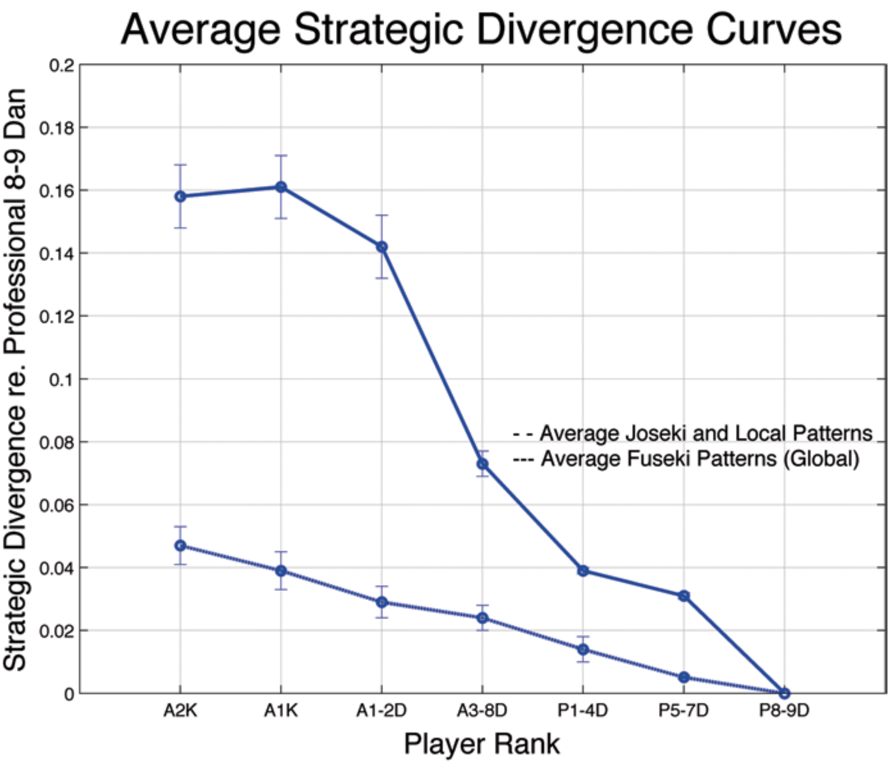


Fig. 6 Illustration of the relative performance on global problems (see text). The bottom line shows the gradual matching of strategy to 9P as a function of rank across diverse problems. The y-axis measures the *difference* from the top experts. The top curve does the same for problems which require *global* understanding. The curve is flat (meaning no improvement) until 1-Dan Amateur (Redrawn from Harré et al. 2011b)

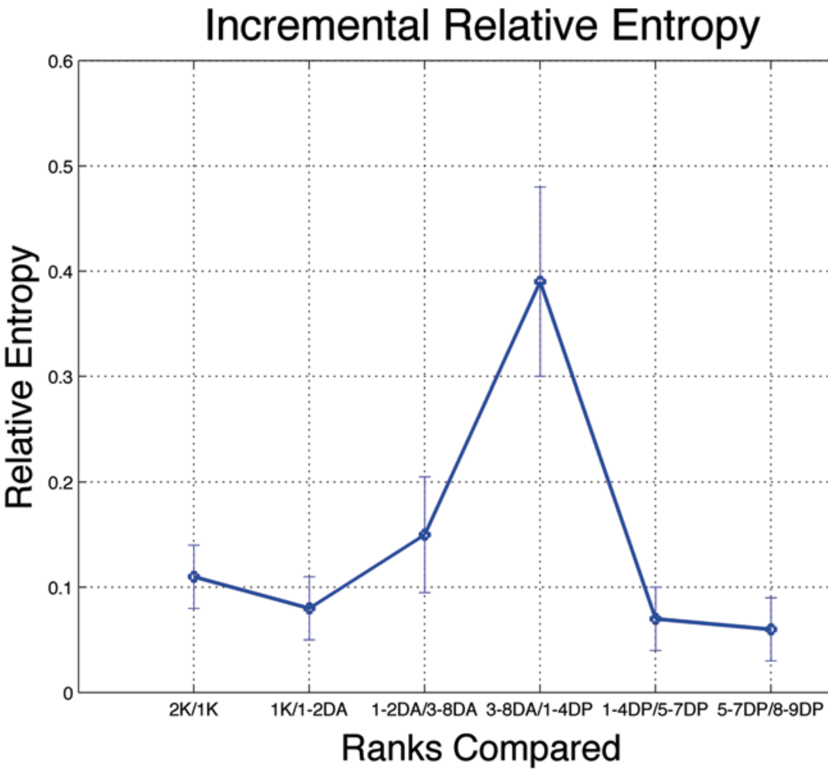


Fig. 7 The expertise flashpoint (Redrawn from Harré et al. 2011b)

on local-global. But comparing adjoining ranks, there is a big peak in difference at the top amateur and low professional ranks. But the overall performance is not changing.

This is more like a rearrangement of how things fit together. Further work established that this was a second-order phase transition by detecting a peak in mutual information (Harré et al. 2011a; Bossomaier et al. 2013).

There is much work to be done, to determine how widespread these transitions are. But the implication for serious games is clear. We want to be able to detect when players have gone through these expertise transitions.

Changing the Building Blocks

The final piece of the story tells us where and what these transitions are. One might assume that they are at very high cognitive levels in the brain. But the reality might be otherwise. Using a technique known as self-organising maps (Kohonen 1982), we determined sets of *perceptual templates*, the low-level primitives by which players group patterns on the board (Harré et al. 2012). It turns out that these templates

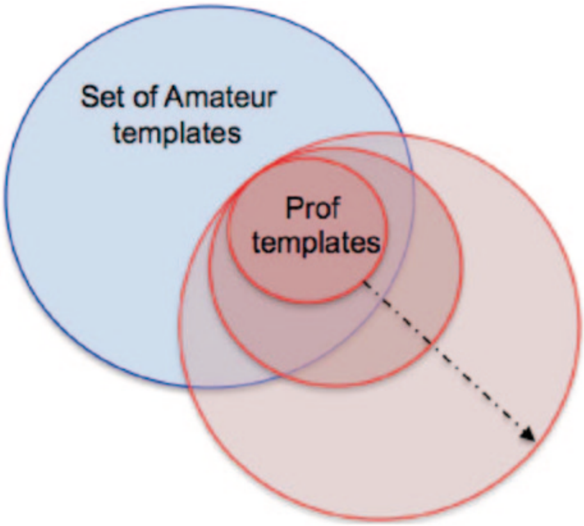


Fig. 8 Amateur and professional templates. As the threshold for frequency of occurrence decreases, more and more professional templates appear which are different from the amateur set. See Harré et al. (2012)

change significantly through the expertise transition. Figure 8 shows the limited overlap of amateur and professional templates.

So, the lowest level filter through which we see the domain changes. It is not so easy to get a feel for this by introspection. But many of the great breakthroughs in science involve a change at the lowest level, quantisation of energy, constancy of the speed of light or realisation that DNA was double helix. But the same happens amongst the great creations in art and humanities, cubism, equal temperament scale or squeezing paint, seemingly at random, but maybe fractally onto giant canvases, a technique made famous by Jackson Pollock.

A potential use of these findings within serious games is to get players to learn the templates of experts much earlier. It is not too difficult to imagine ways this might be done, but it is a completely open area of research. It might be that only through stumbling through some of the blind alleys that the royal road to expertise will become apparent.

Big Brother is Watching: Quiet Assessment

A recent innovation in thinking about learning, especially in the games context, is the idea of watching how people play, and measuring their performance *in situ*. Valerie Shute, who introduced the term in 2005, acknowledges its *sine nomine* use two decades earlier. Webb et al. (2013) prefer the term *quiet assessment*, to avoid the furtive implications of the former.

Knewton (a collection of Knerds) is a data analytics company putting computational teeth into student learning—to study individual learning and make it adaptive. Its founder, Jose Ferreira, points out in his company blog, that there are huge data resources waiting to be tapped:

> Only recently have advances in technology and data science made it possible to unlock these vast data sets. The benefits range from more effective self-paced learning to tools that enable instructors to pinpoint interventions, create productive peer groups, and free up class time for creativity and problem solving. (Ferreira 2013)

Computer games, along with some other digital media, offer tremendous possibilities for watching how we learn, giving us a gentle prod when we go off track, helpful little avatars popping up when we need a hint and a totally new level of personalised tuition. We saw above that if we have records of the decisions people make, we can track their progression from novice to expert.

But here, at the start of the second decade of the twenty-first century, we have hit a serious problem, discussed at length by Hickey and Zuiker (2012). We have entered an era of testing, national testing, even global standards. The US *No Child Left Behind* supported a narrowing of testing, which in turn led to increasing stress on teachers created by these outcomes of these tests, what Webb et al. (2013) describe as *high stakes assessment*. Hickey and Zuiker (2012) point out that the drive for the readily testable and the effectiveness of simple drill-like exercises (and we could suggest that a lot of gamification would fit into this category) interfere or conflict with *assessment for learning*.

We saw something of this dichotomy in the TEEM report above. The rich multilevel feedback, which we could potentially get from computer games, may not fit in with teacher priorities imposed by national curricula. Specifically in maths and English, studies have found that assessment practices were weak (Webb et al. 2013) and even hint that teachers may not be given sufficient opportunity to be involved in assessment design.

At the time of writing (mid-2014) the world is awash with professional failings, driving increased monitoring and accreditation. The work of rogue traders and other crafty operators betting on the collapse of sub-prime mortgages and other shaking financial instruments, created the Global Financial Crisis (GFC) and brought us very, very close to a global economic meltdown. The UK National Health Service, lauded by Danny Boyle in the opening of the London Olympics, is suffering one crisis after another, as one hospital after another fails to meet basic standards.

But these large-scale challenges go beyond conventional training. Some of the people making the decisions which led to the GFC were highly qualified. Serious games have the potential to monitor expertise in a rich, realistic context and provide ongoing updating and measurement of performance amongst established practitioners. This is another open area of research.

Envoi

Video games are a major feature of twentieth century life. They occupy a big chunk of leisure activity and show huge promise for learning and education. They have an established track record in skill development, such as learning to fly, drive or operate something. They show a lot of promise in many areas of the school and university curriculum.

But the real excitement of this growing area of serious games is the complex environment surrounding the game, the meta-game and affinity spaces. This rich, creativity extension of the gaming world offers in-depth, contextualised understanding. One of the huge gains, and possibly, one of the challenges, is integrating these powerful frameworks into conventional courses and educational programs:

> …the symbols and formulas of the Glass Bead Game combined structurally, musically and philosophically within the framework of a universal language, were nourished by all the sciences and arts….—The Glass Bead Game

Acknowledgements The development of the CADGE game engine and CRASL language were funded by the Australian Research Council grant LP0775418 in conjunction with the Australian Defence Force. Work on expertise was carried out under grant DP0881829.

References

Anderson, J., & Rainie, L. (2012). Gamification: Experts expect ‘game layers’ to expand in the future with positive and negative results. Technical report, Pew Research Center.

Anderson, A., Huttenlocher, D., Kleinberg, J., & Leskovec, J. (2013). Steering user behavior with badges. In Proc. International WWW Conference (pp. 95–106).

Anguera, J. A., Boccanfuso, J., Rintoul, J. L., Al-Hashimi, O., Faraji, F., Janowich, J., Kong, E., Larraburo, Y., Rolle, C., Johnston, E., & Gazzaley, A. (2013). Video game training enhances cognitive control in older adults. *Nature, 501,* 97–101.

Bavelier, D., Green, C. S., Pouget, A., & Schrater, P. (2012). Brain plasticity through the life span: Learning to learn and action video games. *Annual Review of Neuroscience, 35,* 391–416.

Bogost, I. (2008). The rhetoric of video games. In *Rules of play* (pp. 117–140). Cambridge: MIT Press.

Bogost, I. (2011). *Gamification is bullshit*. http://www.bogost.com/blog/gamification_is_bullshit.shtml. Accessed 6 Feb 2015.

Boot, W. R., Kramer, A. F., Simons, D. J., Fabiani, M., & Gratton, G. (2008). The effects of video game playing on attention, memory, and executive control. *Acta Psychologica, 29,* 387–398.

Bossomaier, T., & Green, D. (Eds.). (2000). *Complex systems*. Cambridge: Cambridge University Press.

Bossomaier, T., Barnett, L., & Harré, M. (2013). Information and phase transitions in socio-economic systems. *Complex Adaptive Systems Modeling, 1*(9), 1–25.

Buzzmath. (2014). *Middle school math practice. Anytime, anywhere*. https://www.buzzmath.com.

Carr, D., & Bossomaier, T. (2011). Relativity in a rock field: A study of physics learning with a computer game. *Australasian Journal of Educational Technology, 27*(6), 1042–1067.

Carroll, J., & Cameron, D. (2005). Playing the game: Role distance and digital performance. *Applied Theatre Researcher, 6*(1), 1–11.

Carroll, J., Anderson, M., & Cameron, D. (2006). *Real players?: Drama, technology and education*. Stoke on Trent: Trentham Books.

Castro, M. Vd., Bissaco, M. A. S., Panccioni, B. M., Rodrigues, S. C. M, & Domingues, A. M. (2014). Effect of a virtual environment on the development of mathematical skills in children with dyscalculia. *PLoS ONE, 9*(7), e103354.

Central LBP. (2013). LittleBigPlanet. http://www.littlebigplanet.com/. Accessed 11 Feb 2015.

Chen, J. (2007). Flow in games (and everything else). *Communications of the ACM, 50*(4), 31–34. doi:10.1145/1232743.1232769. http://www.jenovachen.com/flowingames/p31-chen.pdf. Accessed 6 Feb 2015.

Clements, D., & Samara, J. (2011). Early childhood mathematics intervention. *Science, 333,* 968–970.

Coombs, W. (2007). *Ongoing crisis communication: Planning, managing, and responding*. London: SAGE Publications Inc.
Cross, T. (2011, December 10). All the world's a game [Special report: Video games]. *The Economist*.
Csíkszentmihályi, M. (1990). *Flow: The psychology of optimal experience*. New York: Harper & Row.
Deci, E. (1971). Effects of externally mediated rewards on intrinsic motivation. *Journal of Personality and Social Psychology, 18*(1), 105–115.
Deci, E., & Ryan, R. (2008). Facilitating optimal motivation and psychological well-being across life's domains. *Canadian Journal of Psychology, 49*(1), 14–23.
de Freitas, A. A., & de Freitas, M. M. (2013). Classroom Live: A software-assisted gamification tool. *Computer Science Education, 23,* 186–206.
Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to gamefulness: Defining gamification. In Proc. MindTrek, '11 (pp. 9–15).
Echeverri, J., & Sadler, T. (2011). Gaming as a platform for the development of innovative problem-based learning. *Science Education, 20*(1), 44–48.
Economist-Anonymous. (2013, June 29). Catching on at last [Briefing: Educational technology]. *The Economist, 407*(8842). http://www.economist.com/news/briefing/21580136-new-technology-poised-disrupt-americas-schools-and-then-worlds-catching-last. Accessed 6 Feb 2015.
Erdös, P., & Rényi, A. (1960). On the evolution of random graphs. *Publications of the Mathematical Institute of the Hungarian Academy of Sciences, 5,* 17–61.
Ferreira, J. (2013, July 18). Big data in education: The 5 types that matter. *The Knewton Blog*. http://www.knewton.com/blog/ceo-jose-ferreira/big-data-in-education/. Accessed 6 Feb 2015.
Financial-Football. (2013). Financial football. www.practicalmoneyskills.com/games. Accessed 6 Feb 2015.
Fitz-Walter, Z., Tjondronegoro, D., & Wyeth, P. (2011). Orientation passport: Using gamification to engage university students. In Proc. OZCHI'11 (pp. 122–125).
Gardner, M. (1970). The fantastic combinations of John Conway's new solitaire game 'life'. *Scientific American, 223,* 12–123.
Gartner. (2011). Report on gamification. http://www.gartner.com/newsroom/id/1629214. Accessed 6 Feb 2015.
Gee, J. P. (2003). What video games have to teach us about learning and literacy. *Computers in Entertainment, 1*(1), 20–20. doi:10.1145/950566.950595. http://doi.acm.org/10.1145/950566.950595. Accessed 6 Feb 2015.
Gee, J. P. (2005). Social semiotic spaces and affinity spaces: From the age of mythology to todays schools. In D. Barton & K. Tusting (Eds.), *Beyond communities of practice*. New York: Cambridge University Press.
Girard, C., Ecalle, J., & Mangant, B. (2013). Serious games as new educational tools: How effective are they? A meta-analysis of recent studies. *Journal of Computer Assisted Learning, 29*(3), 207–219.
Gobet, F., & Simon, H. (2000). Five seconds or sixty? Presentation time in expert memory. *Cognitive Science, 24,* 651–682.
Grant, A. (2011). The problem with financial incentives and what to do about it. Technical Report, Wharton Business School.
Groot, A. D., & Gobet, F. (1996). *Perception and memory in chess: Heuristics of the professional eye*. Assen: Van Gorcum.
Hakulinen, L., Auvinen, T., & Korhonen, A. (2013). Empirical study on the effect of achievement badges in TRAKLA2 online learning environment. In Proc. IEEE Learning and Teaching in Computing and Engineering (pp. 47–54).
Harré, M., Bossomaier, T., Gillett, A., & Snyder, A. (2011a). The aggregate complexity of decisions in the game of Go. *European Physical Journal B, 80,* 555–563.
Harré, M., Bossomaier, T., Ranqing, C., & Snyder, A. (2011b). The development of human expertise in a complex environment. *Minds and Machines, 21,* 449–464.
Harré, M., Bossomaier, T., & Snyder, A. (2012). The perceptual cues that reshape expert reasoning. *Nature Scientific Reports, 2*(502). doi:10.1038/srep00502.

Hays, R. (2005). The effectiveness of instructional games: A literature review and discussion. Technical Report 2005-004, Naval Air Warfare Center Training Systems Division Orlando, FL 32826-3275.
Heath, R., & Millar, D. (Eds.). (2004). *Responding to crisis: A rhetorical approach to crisis communication*. New Jersey: Lawrence Erlbaum Associates.
Heathcote, D. (1991). *Collected writings on education and drama*. Evanston: Northwestern University Press.
Heathcote, D. (2002). *Contexts for active learning: Four models to forge links between schooling and society*. Birmingham: NATD Conference.
Heathcote, D., & Bolton, G. (1995). *Drama for learning: Dorothy Heathcote's Mantle of the Expert approach to education*. Portsmouth: Heinemann.
Hesse, H. (1943). *The Glass Bead Game*. Penguin, Translated by Richard and Clara Winston.
Hickey, D., & Zuiker, S. (2012). Multilevel assessment for discourse, understanding, and achievement. *Journal of Learning Sciences, 21*(4), 522–582.
Holt, R. (2000). Examining video game immersion as a flow state (B.A. thesis). Department of Psychology, Brock University, St. Catharines, ON.
Houtari, K., & Hamari, J. (2012). Defining gamification: A service marketing perspective. In Proc. MindTrek (pp. 17–22).
Huizinga, J. (1986). *Homo ludens: A study of the play-element in culture*. London: Beacon Press (English translation).
Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proceedings of the National Academy of Sciences, 105*(19), 6829–6833. doi:10.1073/pnas.0801268105. http://www.pnas.org/content/early/2008/04/25/0801268105.full.pdf+html. Accessed 6 Feb 2015.
Jenkins, H. (2006). *Fans, bloggers and gamers: Exploring participatory culture*. New York: New York University Press.
Ke, F. (2013). Computer-game based tutoring of mathematics. *Computers and Education, 60,* 448–457.
Ke, F. (2014). Am implementation of design-based learning through creating educational computer games: A case study on mathematics learning during design and computing. *Computers and Education, 73,* 26–39.
Kebritchi, M., Hirumi, A., & Bai, H. (2010). The effects of modern mathematics computer games on mathematics achievement and classroom motivation. *Computers and Education, 55,* 427–443.
Kickstarter. (2013). http://www.kickstarter.com/. Accessed 6 Feb 2015.
Klabbers, J. (2009). *The magic circle: Principles of gaming & simulation* (3rd ed.). Rotterdam: Sense Publishers.
Koechlin, E., & Hyafil, A. (2007). Anterior prefrontal function and the limits of human decision-making. *Science, 318,* 594–598.
Kohonen, T. (1982). Self-organized formation of topologically correct feature maps. *Biological Cybernetics, 43,* 59–69.
Laibson, D. (2013, January 22). Education must learn from gaming. *The Economist*.
Landers, R. N., & Callan, R. C. (2011). Casual social games as serious games: The psychology of gamification in undergraduate education and employment training. In M. Minhua, A. Oikonomou, & L. C. Jain (Eds.), *Serious games and edutainment applications*. London: Springer.
Lastowka, G. (2013). Player-authors website. Rutgers university. http://player-authors.rutgers.edu/. Accessed 6 Feb 2015.
Levitt, S., & Dubner, S. (2005). *Freakonomics: A rogue economist explores the hidden side of everything*. New York: William Morrow.
Lindström, P., Gulz, A., Haaker, M., & Sjödén, B. (2011). Matching and mismatching between the pedagogical design principles of a math game and the actual practices of play. *Journal of Computer Assisted Learning, 27*(1), 90–102.
Lupien, S., Maheu, F., Tu, M., Fiocco, A., & Schramek, T. (2007). The effects of stress and stress hormones on human cognition: Implications for the field of brain and cognition. *Brain and Cognition, 65,* 209–237.

McFarlane, A., Sparrowhawk, A., & Heald, Y. (2002). Report on the educational use of games. Technical Report, TEEM. http://www.teemeducation.org.uk. Accessed 11 Feb 2015.
McGonigal, J. (2011). *Reality is broken*. London: Jonathan Cape.
Mozilla. (2014). Open badges. http://openbadges.org. Accessed 6 Feb 2015.
Nagel, T. (1974). What is it like to be a bat? *The Philosophical Review, 83*(4), 435–450.
NASA. (1997). Stress management by bio-feedback. http://spinoff.nasa.gov/spinoff1997/ch1.html. Accessed 6 Feb 2015.
Nicholson, S. (2012). A user-centered theoretical framework for meaningful gamification. Paper Presentation at *Games + Learning + Society 8.0*. Madison, WI.
Ophir, E., Nass, C., & Wagner, A. D. (2009). Cognitive control in media multitaskers. *Proceedings of the National Academy of Sciences of the United States of America, 106*(37), 15583–15587. doi:10.1073/pnas.0903620106. http://www.pnas.org/content/early/2009/08/21/0903620106.full.pdf+html. Accessed 6 Feb 2015.
Perez, S. (2012, June 21). Badgevilles acquires gamification.org, grabs the 'gamification' username on twitter, facebook, youtube. *TechCrunch*. http://techcrunch.com/2012/06/21/badgevilles-acquires-gamification-org-grabs-the-gamification-username-on-twitter-facebook-youtube/. Accessed 6 Feb 2015.
Pettey, C., & van der Meulen, R. (2012). Gartner's 2012 hype cycle for emerging technologies identifies tipping point technologies that will unlock long-awaited technology scenarios. Technical Report, Gartner, Inc.
Pink, D. (2011). *Drive: The surprising truth about what motivates us*. New York: Penguin.
Rieber, L. P. (1996). Seriously considering play: Designing interactive learning environments based on the blending of microworlds, simulations, and games. *Educational Technology Research and Development, 44*(2), 43–58. doi:10.1007/BF02300540.
Robinson, K. (2009). *The element: How finding your passion changes everything*. United States: Viking Penguin Group.
Ross, M. (2010). Case study: Math teacher uses gamification to help at-risk students succeed. http://www.teachthought.com/trends/a-case-study-in- gamification/. Accessed 6 Feb 2015.
Salen, K., & Zimmerman, E. (2004). *Rules of play*. Cambridge: MIT Press.
Schiller, F. (1794). Ueber die ästhetische Erziehung des Menschen, in einer Reihe von Briefen. http://gutenberg.spiegel.de/buch/3355/3. Accessed 6 Feb 2015.
Shaffer, D. W. (2004). Epistemic frames for epistemic games. *Computers and Education, 46,* 223–234.
Shaffer, D. W. (2006). *How computer games help children learn*. New York: Palgrave Macmillan.
Shannon, C. (1948). A mathematical theory of communication. *The Bell System Technical Journal, 27,* 379–423.
Shonkoff, J. (2011). Protecting brains, not simply stimulating minds. *Science, 333,* 982–983.
Shute, V. (2011). Stealth assessment in computer-based games to support learning. In S. Tobias & J. D. Fletcher (Eds.), *Computer games and instruction* (pp. 503–524). Charlotte, NC: Information Age Publishing.
Simon, H. (1959). Theories of decision-making in economics and behavioural science. *The American Economic Review, 49,* 253–283.
Squire, K. (2006). From content to context: Videogames as designed experience. *Educational Researcher, 35,* 19–29. doi:10.3102/0013189x035008019.
Squire, K. (2008). Open-ended video games: A model for developing learning in the interactive age. In K. Salen (Ed.), *The ecology of games* (pp. 167–198). Cambridge: MIT Press.
Squire, K., Barnett, M., Grant, J. M., & Higginbotham, T. (2004). Electromagnetism Supercharged! Learning physics with digital simulation games. In *Proceedings of the 6th International Conference on Learning Sciences*. International Society of the Learning Sciences. http://www.educationarcade.org/files/articles/Supercharged/SuperchargedResearch.pdf. Accessed 6 Feb 2015.
Strobach, T., Frensch, P. A., & Schubert, T. (2012). Video game practice optimizes executive control skills in dual-task and task switching situations. *Acta Psychologica, 140*(1), 13–24.
Suits, B. (1990). *Grasshopper: Games, life and utopia*. Boston: David R. Godine.

Suits, B., & Hurka, T. (2005). *The grasshopper: games, life and utopia*. Broadview Press. http://books.google.com.au/books?id=EMcDI4m0BpsC. Accessed 6 Feb 2015.

Webb, M., Gibson, D., & Forkosh-Baruch, A. (2013). Challenges for information technology supporting educational assessment. *Journal of Computer Assisted Learning, 29*(5), 451–462.

Terry Bossomaier is Strategic Research Professor of Computer Systems in the Faculty of Business at Charles Sturt University. He graduated from the Universities of Cambridge and East Anglia and has carried out research in diverse areas, from sensory information processing to parallel computation. He is the author/co-author of four books, co-editor of two more and the author of numerous papers. His most recent centres on using information theory to predict tipping points in complex systems. He has had a long-time interest in games and set up the first computer games degree course in Australia, which has been running successfully for over a decade.

Apps: Appropriate, Applicable, and Appealing?

Nigel Calder

Abstract Mobile technologies, and the apps associated with them, are an increasing presence and influence in everyday life. This is also reflected in their burgeoning incidence as a digital pedagogical medium, both in classrooms and for private use. This chapter considers the implications of this growth and how they might best be utilized for the enhancement of mathematical thinking. It traverses present research concerned with digital technologies in mathematics education, their attendant affordances, and digital games, before casting a discerning eye with regards to the appropriateness, applicability and appeal of apps in the teaching and learning of mathematics. While some concerns are raised, the considerable potential of using apps for mathematics learning is clearly evident. How might we optimise this potential?

Keywords Affordances · Apps · Conceptual knowledge · Differentiation of learning · Digital games · Digital pedagogical media · Digital technologies · Dynamic aspects · Engagement · Entitlements · Game context · iPads · Mathematical thinking · Mathematical understanding · Mobile technologies · Motivation · Professional development · Skill development · TPACK · Visual aspects · Visuospatial

Introduction

There has been a proliferation in the availability, and usage, of both tablets and smartphones in educative settings in recent years. While some research has been undertaken, the uptake has been so rapid as to limit the ongoing related research that might inform and validate this transition. Linked to the increase in mobile technology is the growth in apps that can be utilized for learning.

Studies have shown that the use of digital technologies in mathematics education opens up new opportunities for engaging with mathematical concepts and

N. Calder (✉)
Mathematics, Science and Technology Education, University of Waikato,
Tauranga, New Zealand
e-mail: n.calder@waikato.ac.nz

© Springer Science+Business Media Dordrecht 2015

T. Lowrie, R. Jorgensen (Zevenbergen) (eds.), *Digital Games and Mathematics Learning,*
Mathematics Education in the Digital Era 4, DOI 10.1007/978-94-017-9517-3_12

processes. Some mathematics educators contend that they offer the opportunity to re-envisage aspects of mathematical education, along with alternative ways to facilitate understanding (e.g., Borba and Villarreal 2005; Calder 2011). For instance, the visual and dynamic elements of engaging mathematical thinking through digital technologies repositions the types of knowledge and understanding required. Instantly plotting a function and tracing to find a maximum, brings to question the purpose of only using algebra to locate maxima and minima of functions and, at the very least, offers alternative ways to connect with existing approaches to learning. This simultaneously shapes the learning experience in a range of inter-related ways. Borba and Villarreal (2005) argued that information and communication technology (ICT) emphasises the visual aspect of mathematics, and positively changes the status of visualisation in mathematics education. Visualisation is also an influential element of student engagement with relativity concepts in theoretical physics (see Bossomaier chapter). Likewise, the opportunities afforded to the exploration and transformation of data with digital technology reveals fresh approaches to analysing statistics (e.g., Forbes and Pfannkuch 2009).

Borba and Villarreal (2005) discussed the notion of humans-with-media, by viewing them as collectives of learners, media (in various, often collaborating forms) and other environmental aspects, e.g., mathematical phenomena, other humans, other technologies. They are, therefore, alluding to the medium as being significant in the re-organisation of thinking, and as a consequence, understanding.

The affordances of digital technologies for mathematics education are well documented (Brown 2006; Beatty and Geiger 2010) and there has been recognition of the incremental growth of the use of digital technologies reported through transitions in curriculum documents in, for example, New Zealand (Ministry of Education 2007); Singapore (Ministry of Education, Singapore 2006) and Canada (e.g., Ontario Ministry of Education 2005). This emphasis resonates with a corresponding increase in related mathematical educational research and literature, as evidenced in international compilations (Geiger et al. 2012; Hoyles and Lagrange 2010) and conference proceedings.

Although there has been widespread analysis of the use of digital technologies in mathematics education, from the adaption of software for mathematical purposes, software and hardware developed specifically for mathematics contexts, and online learning in mathematics, the use and associated research regarding the implementation of mobile digital technologies is still in the early stages of development and consideration. Nevertheless, the availability of apps and their inclusion into classroom programs continues relatively unrestrained, and often escapes critical examination. Apps predominantly present the mathematical ideas and processes in a game context, often with extrinsic motivators, which use points as rewards.

Learning through apps offers potential affordances for learning that are similar to those identified within other digital technologies. Apps offer the opportunity to engage dynamically, thus gaining instantaneous feedback to input; moreover, they can link various forms of information or data (e.g., numeric, symbolic, and visual) and transform them simultaneously. They also have the propensity to manipulate large amounts of 'untidy' data, while simultaneously delivering a visually stimulating environment.

Fig. 1 A student game designed using Scratch an interactive programming software

Influences by digital pedagogical media on student motivation and the facilitation of cognitive risk taking have also been reported (e.g., Higgens and Muijs 1999), with relational knowledge and conceptual links enhanced (Santos-Trigo and Moreno-Armella 2006). Do these affordances and associated influences resonate with the use of mobile technology apps in the learning process, and do they affect the ways in which mathematical thinking and understanding is facilitated and processed?

Games have frequently and historically been part of the mathematical learning experience (Bragg 2011). The use of digital games in mathematics learning has been reported to facilitate engagement with spatial elements and 3D visualisation (Lowrie 2005). Multiple representations, through interactive digital environments such as applets, and the designing of games, have also enhanced the learning process (Boon 2006; Confrey et al. 2006; Fig. 1).

There are indications that the use of apps has a positive influence on both attitudes to mathematics learning and student motivation (Attard and Curry 2012; Morgan 2013; Whyte 2012) in both preschool and primary school settings. While this is a key attribute in the engagement of learners and their subsequent learning, optimizing learning is also contingent on the appropriateness and quality of the activity that the learner is being engaged with.

An analysis of apps available through the Apple App Store, which are supposedly designed for mathematical learning, concluded that relatively few supported mathematical learning as advocated by the Australian Curriculum, and that these were predominantly drill-and-practice activities (Larkin 2013). Larkin (2013) identified that mathematical education apps were readily available and cheap to purchase, often being free to the general public without scrutiny. He also reported that they were “often labelled inaccurately; and in a state of flux as new apps are added, renamed, upgraded, or deleted" (p. 432). Other research contends that few apps exemplify current best practice in mathematics education nor do they always integrate visual and dynamic affordances to model mathematics situations that support mathematical sense making (Pelton and Pelton 2012).

Questions have already been raised regarding the appropriateness of the content and pedagogical approaches of apps. This includes those that are used or available in mathematics programs, and within informal learning situations. With this in mind, this chapter will present a closer focus on the application and appeal (motivational aspects) associated with apps.

There are other questions to consider in light of this:

- Does the motivational element of this media engender mathematical engagement in other ways?
- Can key but isolated skills developed through apps be transferred into more contextual situations and investigative approaches?
- Will learners self-evaluate their understanding and select appropriate apps to support or enhance their understanding?
- What is the motivation of those who design and present apps for public consumption: Is it pedagogical or financial? What are the ramifications of this?
- How do the games contexts in apps resonate with other games contexts in terms of engaging learning and facilitating mathematical thinking?
- If apps are an inevitable and relatively enduring element of the evolving digital world, how best might mathematics educators optimise their potential for learning?

The intention of this chapter is not to provide definitive answers to these questions, but to identify and examine existing literature, thereby offering potentially better ways to utilize apps in facilitating mathematical thinking and understanding. Such exploration may also offer potential opportunities to enhance existing educational communities engaged in using apps.

First, let us take a quick scan of the influence of digital technologies in mathematics education generally. For over three decades, digital technologies have been part of mathematics educators' repertoire of tools, knowledge, and processes used to enhance engagement and understanding in learning and teaching (Geiger et al. 2012). While the uptake and approach has been variable, the nature of digital technologies has changed dramatically, along with their usage and availability, which has increased over that time. Interactive whiteboards, tablets such as iPads, virtual learning environments, and smartphones have all come into common use relatively recently, offering opportunities to transform the learning experience. International research echoes and at times initiates these transformations (e.g., Confrey et al. 2010; Geiger et al. 2012; Hoyles and Lagrange 2010). For example, studies have reported their potential to enhance opportunities that enable students to explore and think with 3D geometry (Mackrell 2006; Mackrell and Johnston-Wilder 2005; Yeh 2010). In addition, students engaging mathematical ideas through programming in the interactive environment Scratch enhanced their understanding of spatial movements, while it was simultaneously found to be a productive and motivational environment for facilitating mathematical thinking (Calder and Taylor 2010).

On the other hand, while acknowledging the potential benefits, others caution that opportunities for rich mathematical thinking can be constrained by teachers adhering to prescribed learning trajectories (Zevenbergen and Lerman 2008). Similarly, Chance et al. (2000) reported that visualisation through the ICT medium enhanced understanding of sampling distributions, but that prerequisite knowledge affected students' ability to learn from technology.

While affordances and constraints are often identifiable to particular digital technologies (Sacristán et al. 2010), there are some that are more generically embedded through a range of settings (Calder 2011). Others have indicated that these affordances, when facilitated appropriately by the teacher, may lead to students exploring powerful ideas in mathematics, learning to pose problems, and creating explanations of their own (e.g., Baker et al. 1993; Ploger et al. 1997; Sandholtz et al. 1997). These studies also linked improved high-level reasoning and problem solving to learners investigating in digital environments. In a study of grade-three children using spreadsheets to explore fractional number problems, Drier (2000) reported that the students reinforced and extended their rational number knowledge, while exploring many mathematical concepts in an integrated manner. It follows that conceptualisation of mathematical phenomena, will be different when engaged through each particular software lens. Mariotti et al. (2003) contend, for instance, that a function can be conceptualised differently using Cabri-geometry, an interactive geometry software package (Fig. 2).

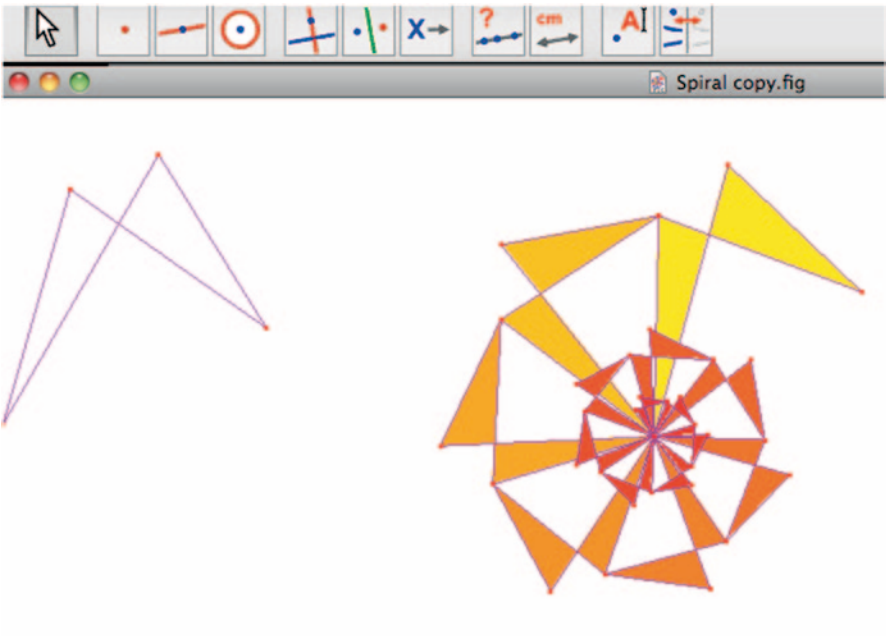


Fig. 2 Cabri-geometry, a dynamic geometry software package

Fig. 3 Mathblaster: Maths skills development activities set in an interactive game

The notion of entitlement describes the opportunities students can expect through engaging school mathematics through ICT media. Six major opportunities have been identified: learning from feedback; observing patterns; seeing connections; working with dynamic images; exploring data; and 'teaching' the computer (Johnston-Wilder and Pimm 2005). Higgins and Muijs (1999) with respect to numeracy, identified two strands of software development: one a behaviourist approach, which focuses on the practice of specific numerical skills, frequently in a game context; the other a constructivist approach, which emphasises understanding of number. The majority of apps available take the first approach with one or two key skills or processes embedded in a simple game context. Meanwhile, using the Internet offers diverse opportunities for learners to engage in specific interactive applets and software (Sinclair 2005). Much of the online interactive materials are in game contexts that focus on one particular mathematical aspect (Fig. 3). While there is human/digital interaction, its purpose is often the development of specific mathematical processes.

Using digital technologies in mathematics learning can also foster risk taking and experimentation (Calder et al. 2006), thus allowing space for students to explore. This exploration requires some shaping however. It may not occur fortuitously. The visual image may provide stimulus, but it is the subsequent thinking that is the key to the learning process. Other researchers have likewise found positive motivational effects by using digital technologies in mathematics programs (e.g., Hoyles 2001; Kulik 1994, in his meta-analysis of computer-based learning; Lancaster 2001; Sandholtz et al. 1997; Schacter and Fagnano 1999).

Digital Games as a Learning Environment

Digital games are utilized in a number of educational settings, often for the development of particular skills within an online applet or a mobile technology app, but there are also a proliferation of digital action games that many students engage with recreationally. These are often set in complex 3D virtual worlds that require the gamer to position themselves, and interact, within these virtual 3D spaces. We will consider them and the associated research first, and then reflect on the relationship with other digital games, before undertaking a more in-depth consideration of mobile technology apps.

The most examined and discussed aspect of digital action games, and the opportunities they afford to enhance mathematical thinking, is in the area of spatial awareness. In particular, this involves moving within or through these virtual worlds, often anticipating the actions of other characters; it can include elements of location, and the representation of 3D space in two dimensions (Fig. 4).

Games contexts and the practice of games can significantly enhance spatial performance (Clements et al. 2008). Others have also recognised or reported that spatiality is an essential aspect of understanding and playing digital games (Avraamidou et al. 2012; Hwang et al. 2008; McGregor 2007). The enhancement of visuospatial reasoning has also been reported (Green and Bavelier 2006; Sims and Mayer 2002). Visuospatial reasoning involves the cognitive functions that analyse and interpret

Fig. 4 A representation of 3D space in two dimensions in Mario Kart Wii (Source: http://themushroomkingdom.net/images/ss/mkwii/045.jpg. Accessed 27 Feb 2015)

space, including the world around us, in two or three dimensions. It utilizes mental imagery and navigation, distance and depth perception, and visuospatial construction. Visuospatial functions are considered to be one of the brain's highest levels of visual processing (Brain Centre America 2008). Lowrie (2005), in a study involving the Pokémon game, reported that the students utilized visuospatial reasoning to solve problems and interpret a variety of maps.

Calder and Taylor (2010), in a study where students used a programming language Scratch to design games, similarly reported that the students' spatial awareness was enhanced not only through using location and spatial movement in the process of designing the games, but also while engaged with playing, trialling, and modification. Implicit to successfully playing digital games is the ongoing prediction, reflection, and revision of strategies (Van Eck 2006). The nature of the games environment determines that these skills and processes require visuospatial reasoning.

The context, as enacted through the backstory, located the game or activity within the students' cultural world and evoked their initial purpose for engagement (Ainley et al. 2006). They also contend that to build purpose into the activity, the mathematics needs to be either an implicit element or a more explicit part of the task that requires completion to continue or reach subsequent levels. It seems reasonable that this would apply to apps games as well where, for instance, moving to a new level of the game might require an explicit process undertaken accurately within a set timeframe.

The inclusion of characters transforms the dynamics of the spatial relationships and diversifies the perspectives the gameplayer might take (Tversky and Hard 2009). It was found that most students took the perspective of the character for actions or movements. This transposition of perspective offers the opportunity for the development of complex visuospatial reasoning, but is probably not directly applicable to apps as they do not typically involve moving and interacting within virtual worlds.

In a 3-year study into the learning of mathematics evoked by playing digital action games, Jorgensen and Lowrie (2012) reported that the games offered many opportunities for mathematical learning. As well though, the data indicated that the primary driver for the practice and development of skills was speed, rather than higher-order thinking. In addition, there was no disincentive for making errors, so players were content to use trial-and-error strategies only, disregarding multiple errors rather than evolving "more complex ways of working through worlds" (Jorgensen and Lowrie 2012, p. 384). Observations of 5-year-olds using apps in their mathematics program, likewise identified that one or two children took a random approach to solving the puzzles, and used low-level repetitive actions rather than those that involved conscious mathematical thinking. For example, the random selection of numbers until the solution is found and the next stage engaged. The related investigation found that the use of apps was highly motivational and engaged the children in learning mathematical processes (Whyte 2012).

This leads us to a more in-depth examination of the use of apps. We will discuss their use, both generally and with regards to facilitating mathematical learning, and with consideration of the extent to which their use is appropriate, applicable, and appealing.

Apps: Are They Appropriate and Applicable?

Mobile technologies offer the potential to transform the learning experience both inside and outside of the classroom. They enable the learning to engage with research and analysis in an ongoing interactive manner, within a variety of settings. For example, in statistics, students can collect data directly in the field and do some exploratory data analysis to inform any immediate review of the data they required, or the approach being used to address their research question. Although situated within a study examining the use of the iPad in literacy learning, Hutchison et al. (2012) identified some advantages and considerations of using iPads that are more generic and would be applicable to learning in mathematics. They contend that iPads power on and off very quickly, so that it is easy to integrate them spontaneously, without disrupting the learning. In addition, students were able to quickly learn to navigate the iPad, and when they did encounter problems, they worked collaboratively to resolve them, leading to enhanced conversations. Also, given the specificity of available apps and the ease of access to iPads in the class situation, teachers were more likely to spontaneously integrate the iPads into their lessons, thus enabling some dynamic, responsive differentiation of the learning for individual students. Lewis et al. (2012), in a study using mobile technologies with the teaching of high school chemistry, likewise found they encouraged group work and interaction.

Research has also reported that iPad usage in primary school mathematics programs has led to greater reflective practice and higher-order thinking (Attard and Curry 2012). They found that it led to enhanced engagement and increased enthusiasm, while also affording opportunities for the teacher to broaden the range of tasks they could integrate into the learning. Carr (2012), in a study with fifth-grade students learning mathematics through the use of iPads and apps, found that their use at times appeared to initiate higher-order thinking and conceptual knowledge by enhancing the students' engagement, practice, and reinforcement of concepts. She also reported that the students were more motivated and engaged compared to a control group not using the mobile technology in their program. iPads also give opportunity for the teacher to differentiate the learning for individuals or groups (Dobler 2012; Hutchison et al. 2012; O'Malley et al. 2013) and foster independent learning (Beschorner and Hutchison 2013; O'Malley et al. 2013). However, they also advocated that teacher professional development was an essential part of effective utilization of the mobile technology. Likewise, they identified a need for teachers to be engaged with processes that enabled them to recognise apps that were appropriate for their learning intentions, and which were also conceptually and age appropriate for their students (O'Malley et al. 2013). Consequently, they reported improved mathematics fluency, while also recognising that there were barriers to learning unless there was a high level of technical support.

The range in the ability and confidence of teachers to support learning through this pedagogical media, along with the greater emphasis on entertainment rather than learning with some apps also constrained the learning process. Lewis et al. (2012) similarly reported lost instructional and student engagement due to technical errors, while Attard and Curry (2012) acknowledged that the initial setting up of the apps, and ongoing maintenance of the iPads, were burdensome for teachers and thus presented a barrier for their usage. Another aspect that might influence the implications of the findings is the possibility that in the relatively small amount of research that has been undertaken, both the researchers and the teachers involved are both experienced and willing digital technology users. This imbues them with a greater propensity to envisage opportunities, and potentially allows them to be more positively positioned in terms of engagement and managing issues. Nevertheless, there is a general consensus that the use of mobile technologies is motivational and has potential to enhance the learning experience.

While these attributes support the use of apps to engender greater engagement and motivation in mathematics learning, it needs to be recognised that, when considering whether apps are applicable and appropriate, this is conditional on the apps selected, the purpose intended, and the pedagogical processes in which they are used.

The number of apps available for mobile technologies has grown rapidly. Jonas-Dwyer et al. (2012) reported that there were 454,966 available through iTunes alone, while in evaluative appraisal of mathematical apps, Larkin (2013) identified that 13 % of apps in the education category available on iTunes were mathematical in conceptual content. There are, therefore, many apps that purport to being designed for mathematics learning. Many of these are for the practice of particular skills in hierarchical, rewards-based games (Attard and Curry 2012; Highfield and Goodwin 2013; Larkin 2013). Attard and Curry (2012) found that they encouraged the students to be behaviourally and affectively engaged but also acknowledged that this did not necessarily translate to mathematical cognitive engagement. While the use of apps can offer potential for the differentiation of learning there can often be a “mismatch between ability and task” (Attard and Curry 2012, p. 80). This might be due to the volume and breadth of choice, and the frequently inaccurate description and promotion of apps. These aspects, in conjunction with time constraints on teachers, can lead to inaccurate teacher research and the mismatch of the appropriate app to the students’ learning trajectories. However, it might also derive from a lack of sufficient teacher technological pedagogical content knowledge (TPACK) to match the activity appropriately to the individual situation. Teachers need to consider which apps might actually enhance the mathematical learning of their students at the appropriate and optimal time, rather than just considering whether the students are engaged and working independently. TPACK, in this context, takes time and personal experience to evolve. There is often not enough time available for individual teacher’s development within the tight constraints of their teaching programs, even when the teacher has positive intentions. Either way, there appears to be a need for teacher professional development (Attard 2013) and the evaluation of apps by professional bodies (Larkin 2013) so that teachers might undertake more effective differentiation of learning through their use. The fluid nature of apps development also indicates the need for effective filtering systems for both teachers and parents (Highfield and Goodwin 2013).

While educational apps are frequently game based (Carr 2012; Murray and Olcese 2011) and engaging, it is also important in mathematics education apps that the mathematics learning opportunities are embedded seamlessly within the playing of the games (Masek et al. 2012). For instance, students playing a game using geometry and measurement within problem solving contexts, rather than having the solving of a single unrelated mathematics problem enabling them to move to the next level. With the appropriate structure, apps have the potential for affective and cognitive engagement, while the affordances of interactivity and instantaneous feedback they offer, foster the learner's willingness to take risks within their learning. If the students are not working completely individually, then they can also promote active discussion (Van de Walle et al. 2010). Carr (2012) also contends that multiple senses are incorporated with the use of apps, and that they might reinforce learning and support a variety of objectives. In terms of one current agenda in mathematics education, to use activities to evoke mathematical thinking, apps appear to have limitations, with few apps supporting innovative teaching/learning practices (Murray and Olcese 2011; Pelton and Pelton 2012).

Carr (2012) also concluded that there were mixed results regarding the influence of mobile device usage on mathematical conceptual understanding and academic success, while also acknowledging that most research studies had been short term, and thus less likely to induce statistically significant attributable differences. In her study, examining the mathematics achievement of grade-five students when engaged through game-based apps, Carr (2012) acknowledged the limitations of the findings, with the students only having access to the iPads in mathematics lessons for over 40 days. She advocated that students be allowed to have 24-h access, 7 days a week to get a more valid indication of their effectiveness. She also referenced Silvernail and Gritter (2004), who claimed that it might take up to 8 years before the implementation of a new technology would have an identifiable effect.

There is also evidence that supports the use of apps in learning programs and the contention that, if used appropriately, they enhance mathematical thinking. In situations as diverse as a Hong Kong primary school setting (Li and Pow 2011), a New Zealand primary school (Morgan 2013), and a Californian middle school (Houghton Mifflin Harcourt 2012), studies reported positive effects on student achievement. While finding the results of her study inconclusive regarding a significant impact, Carr (2012) nevertheless recognised that apps could shape student academic success, and that game-based learning apps offer the potential to enable mathematical understanding and problem solving processes.

An element of learning through digital games, and one that is often criticised, is their tendency to promote repetitive practice of skills. However, the context and engagement elements of learning through this pedagogical medium present an alternative perspective to what is frequently considered detrimental to the facilitation of mathematical thinking. This relates to the practice principle, as discussed by Jorgensen and Lowrie (2012). They assert that in these learning environments the nature of the gaming context promotes lots of practice of key skills, but not to the detriment of student engagement. In other words, the practice is embedded within the virtual worlds that the learners engage with on their own terms, hence they are motivated and the learning does not become boring. These contexts frequently utilize visual, sound, and movement elements that learners also might find highly

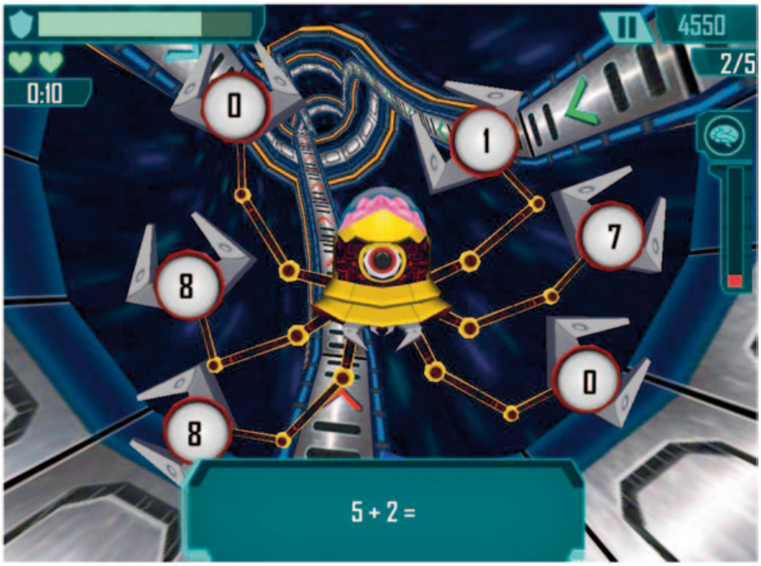


Fig. 5 Mathblaster, where basic skills are developed in a highly engaging context

engaging. They also argue that students are on task for significant periods of time. They try, and then modify strategies to make the most efficient progress, even if the strategies are frequently trial-and-error by nature (Jorgensen and Lowrie 2012; Fig. 5).

Apps are readily available outside of the school setting, and this, combined with their relatively cheap cost (many are free), furthers the need for educational scrutiny as well as the engagement or fun aspect. Do the general public have the expertise to differentiate between the educational and entertainment elements of an app, or to recognise either? This constraint to the learning process is applicable to teachers too. In utilizing diagnostic frames to evaluate the validity of apps, Larkin (2013) reduced an initial 4000 mathematical apps that were available in iTunes, to 34 that he considered met the educative criteria of being facilitative of conceptual knowledge and promoting the mathematical processes of reasoning, representation, and sense making. He also found that many of the descriptions were incongruous with the actual encounter, reporting that the mathematical content, the nature of the activity, and the age appropriateness were often inaccurate.

This also highlights the motivation of the apps designer. If optimal mathematical engagement or understanding is their motivation, then the structure and nature of the activity will differ from someone who is purely trying to optimise profit. A strategy for optimising profit might be to position the promotion and pricing of the app so that there is maximum international downloading. That is, if the initial visual engagement with the apps is highly appealing, the learning it promises is appropriate, and the price sufficiently low, then many potential users will download it and then evaluate its usefulness or fit for purpose after paying for it. The apps may be easily discarded or remain relatively unused, if it proves to be inappropriate or ineffective to the purchaser. However, the designer has nevertheless attained their desired objective—to make more money!

It is apparent that, conditional to the nature and quality of the app, and the matching to particular individual learning trajectories, mathematical apps can certainly be appropriate and affective. On the other hand, the indiscriminate use of mathematical apps without teacher research and TPACK, is most likely going to be ineffective in supporting teacher learning objectives for the students. While there are many primary and secondary schools investing in a range of newer, more mobile technologies such as iPads and iPods, teachers are often expected to integrate the technologies into teaching and learning without the support of professional development, particularly in relation to using the technology to enhance teaching, learning, and student engagement (Attard and Curry 2012). It seems a disproportionate allocation of resource, if the vast bulk is allocated to hardware, while two of the key aspects in enhancing the students' learning are neglected. The nature of the learning experience, through engagement with the apps, might be determined by what is free or cheapest, rather than what is most pedagogically appropriate. The professional growth of the teachers and the ongoing evolution of their TPACK may be given far less priority than the acquisition of hardware. This would be detrimental to the optimisation of the students' mathematical learning.

There are some excellent apps that foster mathematical learning, and there are teachers who have the knowledge and propensity to use them very effectively, but it is dependent on these two conditions both being evident for effective learning to occur. The next section focuses on the affective elements of learning through mathematical apps.

Apps: Do They Appeal?

As indicated in earlier sections, apps offer the potential for affective engagement. They can foster positive attitudes to mathematics learning and be highly motivational across a range of contexts and ages (Attard and Curry 2012; Morgan 2013; Whyte 2012). In a 6-month trial that integrated iPads into classroom practice, Attard and Curry (2012) reported that all of the students were positive about the experience, and that the teacher indicated that this had led to improved engagement with the mathematics.

Much of the discourse regarding how the use of iPads and apps influences the affective elements of the learning experience, centres on the notion of student engagement; of students being actively enthralled and motivated, often by the visual and interactive characteristics of the pedagogical medium (Carr 2012; Hill 2011; Li and Pow 2011; Price 2011). An increased motivation to learn and an indication of students being more attentive in class have also been reported (Houghton Mifflin Harcourt 2012; Li and Pow 2011).

The inclusion of mathematics game-based apps in a mathematics program has likewise enhanced engagement and is reported to have increased enthusiasm and participation (Attard and Curry 2012; Attard 2013). In a study of students with disabilities and their fluency when using mathematics, O'Malley et al. (2013), contend that the use of iPads had a positive influence on students and on their engagement and interest in their work. This resonates with research that examined iPad use in other curriculum areas. For instance, Lewis et al. (2012) found that their use motivated chemistry students. They reported in their study that the students overall experience of utilizing apps within their learning program was positive.

Meanwhile, others have indicated that the use of digital games led to active discussion and inter-student interaction and collaboration (Murray and Olcese 2011; Van de Walle et al. 2010). Mathematical games were also reported to evoke student interest with tasks that were otherwise perceived to be repetitive and boring (Carr 2012).

Concluding Thoughts

While the research indicates considerable potential for iPad apps to positively influence the learning experience through their inclusion in mathematics teaching and learning programs, it also points towards some important considerations. The use of mathematics apps, across a range of contexts and age levels enhanced learning generally, but this was determined to some extent by the appropriateness and applicability of the apps to the particular student, their learning trajectory and the suitability of the app to the particular learning situation. The vast number and continued proliferation of available apps and the relative ease of access to them, indicates the need for ongoing critical review of their content. Do the descriptions of the apps match their actual delivery? Are they age appropriate? This takes considerable pedagogical content knowledge in mathematics education, while also including experience and discriminatory critique of the actual usability of the app. Teachers constrained by the immediacy of the learners' requirements in their classes and considerable time constraints, do not often have the time, nor expertise, to undertake this evaluation with every seemingly appropriate app. This implies that some coordination of resources is required, not only within and between schools, but also at broader regional or national levels. Larkin (2013) has suggested and intends to initiate a dynamic ongoing database that will hopefully address this to some extent. This also indicates the need for both the inclusion of apps awareness in pre-service teaching programs and within teacher professional development in this area.

The research is relatively cohesive in its assertions regarding the appeal of mathematics game-based apps. Students find them engaging and motivational, and advocate their inclusion in programs. Teachers likewise report that their perceptions of the students' learning echo the students. Perhaps there is an element of novelty and a potential for interest without learning, but generally if students are motivated, more engaged, and enjoying an element of learning, they will come to understanding more readily. The challenge in terms of eventual familiarity leading to relative disengagement is to keep the apps as part of a varied program, to ensure that they are relevant and appropriate for the students, and for the development of apps to be ongoing and responsive to critical review. Their suitability for independent, focussed learning also offers opportunity for apps to be developed to extend our most able students—to allow them to individually pace their learning and self-select apps with more challenging concepts or processes.

Today's learners are engaged and generally engrossed by digital media and can use them effectively to communicate, investigate, and process ideas and personal questions. However, just allowing these learners access to mobile technology is not sufficient, nor educationally ethical. It has to be resourced equitably, and have both the learners and the teachers engaged in up-skilling to enable effective use of mathematics apps. Effective utilization also requires having both teachers and students involved in their ongoing evaluation and dynamic development. Mathematics educators and students need to be influential in the development of apps and the ways they are used in the learning process. If the interrelated pedagogical aspects and mathematical thinking are given primacy, then apps can certainly be appropriate, applicable, and appealing.

References

Ainley, J., Pratt, D., & Hansen, A. (2006). Connecting engagement and focus in pedagogical task design. *British Educational Research Journal*, *32*(1), 23–38.

Attard, C. (2013). Integrating iPads into primary mathematics pedagogies: An exploration of two teachers' experiences. In V. Steine, L. Ball, & C. Bardini (Eds.), *Mathematics education: Yesterday, today and tomorrow* (Proceedings of the 36th annual conference of the Mathematics Education Research Group of Australasia). Melbourne, Australia: MERGA.

Attard, C., & Curry, C. (2012). Exploring the use of iPads to engage young students with mathematics. In J. Dindyal, L. P. Cheng, & S. F. Ng (Eds.), *Mathematics education: Expanding horizons* (Proceedings of the 35th annual conference of the Mathematics Education Research Group of Australasia). Singapore: MERGA.

Avraamidou, A., Monaghan, J., & Walker, A. (2012). Abstraction through game play. *Technology, knowledge and learning*: *Learning mathematics, science and the arts in the context of digital technologies*, *17*(1–2), 1–21.

Baker, E. L., Gearhart, M., & Herman, J. L. (1993). Assessing Writing Portfolios: Issues in the validity and meaning of scores. *Educational Assessment, 1*(3), 201–224.

Beatty, R., & Geiger, V. (2010). Technology, communication, and collaboration: Re-thinking communities of inquiry, learning and practice. In C. Hoyles & J.-B. Lagrange (Eds.), *Mathematics education and technology—Rethinking the terrain* (pp. 251–284). New York: Springer.

Beschorner, B., & Hutchison, A. (2013). iPads as a Literacy Teaching Tool in Early Childhood. *International Journal of Education in Mathematics, Science and Technology (Online Submission), 1,* 16–24.

Boon, P. (2006). Designing didactical tools and microworlds for mathematics education. In C. Hoyles, J.-B. Lagrange, L. H. Son, & N. Sinclair (Eds.), *Proceedings of 17th ICMI study conference, Technology Revisited* (pp. 38–45). Hanoi: Hanoi University of Technology.

Borba, M. C., & Villarreal, M. E. (2005). *Humans-with-media and the reorganization of mathematical thinking: Information and communication technologies, modeling, visualization and experimentation*. New York: Springer.

Bragg, S. (2011). "Now it's up to us to interpret it": "Youth voice" and visual methods. In P. Thomson & J. Sefton-Green (Eds.), *Researching creative learning: Methods and issues* (pp. 88–103). New York: Routledge.

Brain Centre America. (2008). *Brain Functions: Visuo-spatial skills*. http://www.braincentreamerica.com. Accessed 17 May 2013.

Brown, J. (2006). Manifestations of affordances of technology-rich teaching and learning environment (TRTLE). In J. Novotná, H. Moraová, M. Krátká, & N. Stehliková (Eds.), *Mathematics in the centre* (Proceedings of the 30th conference of the International Group for the Psychology of Mathematics Education, pp. 241–248). Prague, Czech Republic: PME.

Calder, N. S. (2011). *Processing mathematics through digital technologies: The primary years*. Rotterdam: Sense Publishers.

Calder, N. S., & Taylor, M. (2010). *Scratch*ing below the surface: Mathematics through an alternative digital lens? In L. Sparrow, B. Kissane, & C. Hurst (Eds.), *Shaping the future of mathematics education* (Proceedings of the 33rd annual conference of the Mathematics Education Research Group of Australasia, pp. 117–124). Fremantle, Australia: MERGA.

Calder, N. S., Brown, T., Hanley, U., & Darby, S. (2006). Forming conjectures within a spreadsheet environment. *Mathematical Education Research Journal, 18*(3), 100–116.

Carr, J. (2012). Does math achievement h'APP'en when iPads and game-based learning are incorporated into fifth-grade mathematics instruction? *Journal of Information Technology Education, 11*, 269–286.

Chance, B., Garfield, J., & delMas, R. (2000). Developing simulation activities to improve students' statistical reasoning. In M. O. T. Thomas (Ed.), *Proceedings of TIME 2000* (pp. 25–32). Auckland: The University of Auckland and Auckland University of Technology.

Clements, D. H., Sarama, J., Yelland, N. J., & Glass, B. (2008). Learning and teaching geometry with computers in the elementary and middle school. In M. K. Heid & G. W. Blume (Eds.). *Research on Technology and the Teaching and Learning of mathematics: Vol 1. Research Synthesis* (pp. 109–154). Information Age Publishing.

Confrey, J., Maloney, A., Ford, L., & Nguyen, K. (2006). Graphs 'N glyphs as a means to teach animation and graphics to motivate proficiency in mathematics by middle grades urban students. In C. Hoyles, J.-B. Lagrange, L. H. Son, & N. Sinclair (Eds.), *Proceedings of 17th ICMI study conference, Technology Revisited* (pp. 112–119). Hanoi: Hanoi University of Technology.

Confrey, J., Hoyles, C., Jones, D., Kahn, K., Maloney, A., Nguyen, K., & Pratt, D. (2010). Designing software for mathematical engagement through modeling. In C. Hoyles, & J.-B. Lagrange (Eds.), *Mathematics education and technology—Rethinking the terrain* (pp. 19–46). New York: Springer.

Dobler, E. (2012). Using iPads to promote literacy in the primary grades. *Reading Today, December/January*, 18–19.

Drier, H. S. (2000). Investigating mathematics as a community of learners. *Teaching Children Mathematics, 6*(6), 358–362.

Forbes, S., & Pfannkuch, M. (2009). Developing statistical thinking: Teaching and learning. In R. Averill, & R. Harvey (Eds.), *Teaching secondary school mathematics and statistics: Evidence-based practice* (pp. 93–128). Wellington: NZCER Press.

Geiger, V., Forgasz, H., Tan, H., Calder, N., & Hill, J. (2012). Technology in mathematics education. In B. Perry, T. Lowrie, T. Logan, A. MacDonald, & J. Greenlees (Eds.), *Review in mathematics education in Australasia 2008–2011* (pp. 111–141). Rotterdam: Sense Publishers.

Green, C. S., & Bavelier, D. (2006). Effects of action video gameplaying on the spatial distribution of visual selective attention. *Journal of Experimental Psychology: Human Perception and Performance*, *32*(6), 1465–1478.

Higgins, S., & Muijs, D. (1999). ICT and numeracy in primary schools. In I. Thompson (Ed.), *Issues in teaching numeracy in primary school* (pp. 103–116). Buckingham: Open University Press.

Highfield, K., & Goodwin, K. (2013). Apps for mathematics learning: A review of 'educational' apps from the iTunes App Store. In V. Steinele, L. Ball, & C. Bardini (Eds.), *Mathematics education: Yesterday, today and tomorrow* (Proceedings of the 36th annual conference of the Mathematics Education Research Group of Australasia, pp. 378–385). Melbourne, Australia: MERGA.

Hill, R. A. (2011). Mobile digital devices. *Teacher Librarian, 39*(1), 22–26.

Houghton Mifflin Harcourt. (2012). HMH Fuse™ algebra I: Results of a yearlong algebra pilot in Riverside, California. Retrieved from http://www.hmheducation.com/fuse/pdf/hmh-fuse-riversidewhitepaper.pdf. Accessed 17 May 2013.

Hoyles, C. (2001). Steering between skills and creativity: a role for the computer. *For the Learning of Mathematics, 21*(1), 33–39.
Hoyles, C., & Lagrange, J.-B. (2010). *Mathematics education and technology—Rethinking the terrain*. New York: Springer.
Hutchison, A., Beschorner, B., & Schmidt-Crawford, D. (2012). Exploring the use of the iPad for literacy learning. *The Reading Teacher, 66*(1), 15–23.
Hwang, J., Park, H., Cha, J., & Shin, B. (2008). Effects of object building activities in Second Life on players' spatial reasoning. In *Proceedings of the 2nd international conference on Digital Game and Intelligent Toy Enhanced Learning* (pp. 62–69). Banff, Canada, 17–19 November.
Johnston-Wilder, S., & Pimm, D. (2005). Some technological tools of the mathematics teacher's trade. In S. Johnson-Wilder & D. Pimm (Eds.), *Teaching Secondary Mathematics with ICT*. (pp. 18–39). Berkshire: Open University Press.
Jonas-Dwyer, D. R., Clarke, C., Celenza, A., & Siddiqui, Z. S. (2012). Evaluating apps for learning and teaching. *International Journal of Emerging Technologies in Learning, 7*(1), 54–57.
Jorgensen, R., & Lowrie, T. (2012). Digital games for learning mathematics: Possibilities and limitations. In J. Dindyal, L. P. Cheng, & S. F. Ng (Eds.), *Mathematics education: Expanding horizons* (Proceedings of the 35th annual conference of the Mathematics Education Research Group of Australasia, eBook, pp. 378–384). Singapore: MERGA.
Kulik, J. A. (1994). Meta-analytic studies of findings on computer-based instruction. In E. L. Baker & H. F. O'Neill, Jr. (Eds.), *Technology assessment in education and training* (pp. 9–34). Hillsdale: Lawrence Erlbaum.
Lancaster, L. (2001). Staring at the page: The functions of gaze in a young child's interpretation of symbolic forms. *Journal of Early Childhood Literacy, 1*(2), 131–152.
Larkin, K. (2013). Maths education: Is there an app for that? In V. Steinle, L. Ball, & C. Bardini (Eds.), *Mathematics education: Yesterday, today and tomorrow* (Proceedings of the 36th annual conference of the Mathematics Education Research Group of Australasia, pp. 426–433). Melbourne, Australia: MERGA
Lewis, M. S., Zhao, J., & Montclare, J. K. (2012). Development and implementation of high school chemistry modules using touch-screen technologies. *Journal of Chemical Education, 89*(8), 1012–1018.
Li, S. C., & Pow, J. C. (2011). Affordance of deep infusion of one-to-one tablet-PCs into and beyond classroom. *International Journal of Instructional Media*, *38*(4), 319–326.
Lowrie, T. (2005). Problem solving in technology rich contexts: Mathematics sense making in out-of-school environments. *Journal of Mathematical Behaviour, 24,* 275–286.
Mackrell, K. (2006). Cabri 3D: Potential, problems and a web-based approach to instrumental genesis. In C. Hoyles, J.-B. Lagrange, L. H. Sun, & N. Sinclair (Eds.), *Proceedings of 17th ICMI study conference: Technology Revisited* (pp. 362–369). Hanoi: Hanoi University of Technology.
Mackrell, K., & Johnston-Wilder, P. (2005). Thinking geometrically: dynamic imagery. In S. Johnston-Wilder, & D. Pimm (Eds.), *Teaching Secondary Mathematics with ICT* (pp. 81–100). Berkshire: Open University Press.
Mariotti, M. A., Laborde, C., & Falcade, R. (2003). Function and graph in a DGS environment. In N. A. Pateman, B. J. Doherty, & J. Zilliox (Eds.), *Proceedings of the 27th Conference of the International Group of the Psychology of Mathematics Education* (Vol. 3, pp. 237–244). Hawaii: PME.
Masek, M., Murcia, K., & Morrison, J. (2012). Getting serious with iPads: The intersection of game design and teaching principals. *Australian Educational Computing, 27*(2), 34–38.
McGregor, G. L. (2007). Situations of play: Patterns of spatial use in videogames. In B. Akira (Ed.), *Situated Play* (Proceedings of the 2007 Digital Games Research Association Conference, pp. 537–545). Tokyo: The University of Tokyo. Retrieved from http://www.digra.org/dl/display_html?chid=07312.05363.pdf.
Ministry of Education. (2007). *The New Zealand Curriculum*. Wellington: Learning Mia.
Ministry of Education, Singapore. (2006). *Mathematics Syllabus Primary*. Singapore: CP & DD.
Morgan, J. (2013). Personal communication. 4 June 2013.
Murray, O. T., & Olcese, N. R. (2011). Teaching and learning with iPads, ready or not? *TechTrends, 55*(6), 42–48.

O'Malley, P., Jenkins, S., Wesley, B., Donehower, C., Rabuck, D., & Lewis, M. E. B. (2013). *Effectiveness of using iPads to build math fluency*. Paper presented at 2013 Council for Exceptional Children Annual Meeting, San Antonio, Texas.

Ontario Ministry of Education. (2005). Toronto, ON: Queen's Printer for Ontario.

Pelton, F. L., & Pelton, T. (2012). Sharing Strategies With Teachers: iPods in Math Class. In *Society for Information Technology & Teacher Education International Conference* (Vol. 2012, No. 1, pp. 4363–4366).

Ploger, D., Klinger, L., & Rooney, M. (1997). Spreadsheets, patterns, and algebraic thinking. *Teaching Children Mathematics, 3*(6), 330–335.

Price, A. (2011). Making a difference with smart tablets. *Teacher Librarian, 39*(1), 31–34.

Sacristán, A., Calder, N. S., Rojano, T., Santos-Trigo, M., Friedlander, A., & Meissner, H. (2010). The influence and shaping of digital technologies on the learning—and learning trajectories—of mathematical concepts. In C. Hoyles & J.-B. Lagrange (Eds.), *Mathematics education and technology—Rethinking the terrain* (pp. 179–226). New York: Springer.

Sandholtz, J. H., Ringstaff, C., & Dwyer, D. C. (1997). *Teaching with technology: Creating a student centred classroom*. New York: Teachers' College Press.

Santos-Trigo, M., & Moreno-Armella, L. (2006). Students' development of mathematical practices based on the use of computational technologies. In C. Hoyles, J.-B. Lagrange, L. H. Son, & N. Sinclair (Eds.), *Proceedings of 17th ICMI study conference: Technology Revisited* (pp. 495–502). Hanoi: Hanoi University of Technology.

Schacter, J., & Fagnano, C. (1999). Does computer technology improve student learning and achievement? How, when, and under what conditions? *Journal of Educational Computing Research, 20*(4), 329–343.

Silvernail, D. L., & Gritter, A. K. (2004). *Maine's middle school laptop program: Creating better writers*. Gorham, ME: University of Southern Maine.

Sims, V. K., & Mayer, R. E. (2002). Domain specificity of spatial expertise: The case of video game players. *Applied Cognitive Psychology, 16*(1), 97–115.

Sinclair, N. (2005). Mathematics on the internet. In S. Johnston-Wilder & D. Pimm (Eds.), *Teaching Secondary Mathematics with ICT* (pp. 203–218). Berkshire: Open University Press.

Tversky, B., & Hard, B. M. (2009). Embodied and disembodied cognition: Spatial perspective-taking. *Cognition, 110*(1), 124–129.

Van de Walle, J. A., Karp, K. S., & Bay-Williams, J. M. (2010). *Elementary and middle school mathematics:Teaching developmentally* (7th ed.). Boston: Allyn & Bacon.

Van Eck, R. (2006). Digital game-based learning: It's not just the digital natives who are restless. *EDUCAUSE Review*, *41*(2), 16.

Whyte, R. (2012). Personal communication. 14 June 2012.

Yeh, A. (2010). Three primary school students' cognition about 3D rotation in a virtual reality learning environment. In L. Sparrow, B. Kissane, & C. Hurst (Eds.), *Shaping the future of mathematics education* (Proceedings of the 33rd annual conference of the Mathematics Education Research Group of Australasia, pp. 690–697). Freemantle, Australia: MERGA.

Zevenbergen, R., & Lerman, S. (2008). Learning environments using interactive whiteboards: New learning spaces or reproduction of old technologies? *Mathematics Education Research Journal, 20*(1), 107–125.

Nigel Calder is a Senior Lecturer for the University of Waikato based at the Tauranga campus in New Zealand. His research interests are predominantly in the use of digital technologies in mathematics education. Nigel also is interested in student-centred inquiry learning, algebraic thinking, and problem solving. He has expertise in a critical approach to contemporary hermeneutics and participatory action research. His present research projects are: examining the influence of mobile technologies on the attitudes and engagement of 16–18 year old Youth Guarantee students in numeracy and literacy, and how mathematical thinking emerges through student-centred inquiry learning in secondary schools. Nigel also authored the book: *Processing Mathematics through Digital Technologies: The Primary Years* (Sense Publishers, 2011) and has published various book chapters and journal articles.

"An App! An App! My Kingdom for An App": An 18-Month Quest to Determine Whether Apps Support Mathematical Knowledge Building

Kevin Larkin

Abstract In recent years, applications (apps) for iPads are increasingly being used to support learning in primary school contexts. Current estimates put the number of available educational apps at the iTunes store at approximately 500,000. Many of these apps contain mathematical content and purport to improve students' mathematics ability. Despite their availability, overall ease of use, and low price, significant questions remain as to their appropriateness in helping students develop mathematical knowledge. Three quantitative measures, previously used in other research to investigate digital technology use and student learning, were modified to meet the specific demands of evaluating apps. This chapter reports on the findings of a long-term research project that comprehensively reviewed mathematical apps to determine their usefulness for primary school students. It found that although the majority of apps provide little more than *edutainment*, a core group of apps were highly effective in supporting students in their development of mathematics knowledge.

Keywords Mathematics apps · iPad apps · iPad · Primary school mathematics · ICT and mathematics · Digital manipulatives

The Story Thus Far

This chapter is the culmination of an 18-month quest to determine the appropriateness of iPad applications (apps) to support mathematical learning in primary school students. Its purpose is to synthesise the research literature concerning apps and mathematics, and then outline the methodology used to evaluate the appropriateness of 142 apps which, having met initial criteria, were then assessed using three quantitative measures. The outcomes of this chapter include an evaluation of the appropriateness of the apps for developing conceptual, procedural and declarative mathematical knowledge and also an assessment of the validity of using the Haugland Software Evaluation Scale (1999), the Productive Pedagogies

K. Larkin (✉)
School of Education and Professional Studies, Griffith University, Gold Coast, Australia
e-mail: k.larkin@griffith.edu.au

© Springer Science+Business Media Dordrecht 2015
T. Lowrie, R. Jorgensen (Zevenbergen) (eds.), *Digital Games and Mathematics Learning,*
Mathematics Education in the Digital Era 4, DOI 10.1007/978-94-017-9517-3_13

Dimensions (2005), and Gee's Learning Principles (2003) in evaluating mathematical apps.

Determining both the number and the quality of the apps at the iTunes store is problematic. Jonas-Dwyer et al. (2012) and Shuler et al. (2012) independently estimate that in 2012 there were approximately 500,000 apps available. Pelton and Francis Pelton (2012) located approximately 4000 mathematics apps and noted that "while some are commendable, almost all of the rest are simple flashcards, numeric procedures, or mobile textbooks and very few currently available apps have engaged best practices by integrating visual models to support sense-making" (p. 4426). As I have shown elsewhere (Larkin 2013), it is difficult to determine the quality of an app based on information available at the iTunes store as it largely consists of marketing for the app. While this is helpful, such information is provided by the developers and is not 100 % accurate. Because of the minimal amount of information available, exacerbated by the existence of significant time demands on teachers (Leong and Chick 2011), it is likely that teachers are unaware of the existence of quality mathematical apps.

Despite the rapid expansion of the use of apps in the educational domain, there is limited research as to their effectiveness in supporting mathematics learning. Some early research in the use of apps on iPods (Kissane 2011) and iPhones (Yuan et al. 2010) have been conducted. Pelton and Francis Pelton (2011, 2012) conducted research which resulted in them creating a range of applications for the iPhone. Attard and Northcote (2011) and Goodwin and Highfield (2013) presented reviews of categories of apps. Calder (this volume) acknowledges this lack of current research and notes that this has contributed to the ad-hoc implementation of iPads in school contexts. This chapter is the first substantive review of iPad apps, to the author's knowledge, that investigates apps claiming to support the mathematical learning of primary-aged students via the use of three quantitative measures.

The chapter has three aims: first, to critique mathematical apps utilising three quantitative measures previously used in academic research (Haugland Software Developmental Scale, Productive Pedagogies, and Gee's Learning Principles); second, to determine whether these scales—used in other research contexts to evaluate web-based software and digital games—are appropriate for critiquing iPad apps; and third, to generate a range of outputs that will be useful in assisting teachers to make informed choices regarding the use of apps for mathematics education in primary school. Prior to outlining the methodology used, and the findings generated, it is useful to briefly examine the extant literature in relation to the use of Information Communication Technology (ICT), particularly software, to support the teaching and learning of mathematics.

By Way of Background

ICT, when used in developmentally appropriate ways (Haugland and Ruiz 2002; Pelton and Francis Pelton 2011), enhances young students' conceptual and procedural knowledge of mathematics leading to the development of higher order thinking in mathematics (Polly 2011) and improves understanding of number recognition, counting, shape recognition, and composition and sorting (Clements and Sarama 2007). However, although technology has the potential to enhance mathematics teaching and learning, the use of technology in drill-and-practice activities has been negatively associated with student achievement (Polly 2011). McManis and Gunnewig (2012) claim that technology can assist student learning only if it is *developmentally appropriate*, i.e., "responsive to the ages and developmental levels of the children, to their individual needs and interests, and to their social and cultural contexts" (p. 16).

A key element in developmentally appropriate technology is software that enables students to become active participants in their own learning (Haugland and Ruiz 2002). Many apps appear to have the potential to enhance learning opportunities for young users (Pelton and Francis Pelton 2011) but this potential is often unrealised. Haugland (1999) sounds a word of caution regarding the often explicit message of designers and marketers that the use of software will accelerate children's learning. One outcome of this intention is that the software (largely drill and practice) is often at the skill level of children 2 or 3 years older than the target audience. This results in children becoming frustrated and not using the software; or children using the software for rote learning with the net effect being that "their retention of concepts is poor as is their ability to apply the concepts to off computer activities" (Haugland 1999, p. 245).

The literature presented thus far indicates that ICT is an appropriate tool to support mathematical learning with the proviso that the software utilised is *developmentally appropriate* and that opportunities for learning by discovery and by instruction are present (Scanlon et al. 2005). A key difficulty is making a determination of appropriateness; thus a number of generic criteria for software use have been proposed in the literature (see Ntuli and Kyei-Blankson 2011; Potter et al. n.d.). What remains unclear is how to determine the appropriateness of iPad apps. Early research into iPad use appears to indicate that young children "learn to use the devices quickly, independently, and confidently and explore freely" (McManis and Gunnewig 2012, p. 15), that such devices have lower costs (thus increasing the likelihood of uptake in schools), and that mathematics apps "seem to be ideally positioned to present mathematical models and manipulatives to support mathematical play, exploration and sense-making both in the classroom and at home" (Pelton and Francis Pelton 2011, p. 2200). However, what remains a key consideration is how educators can come to grips with the explosion in available applications and determine the usefulness of the apps for mathematical learning.

How Do We Know If It's Good or Not?

It is necessary initially to outline the difficulties involved in any research involving iTunes apps. I provide a detailed account of the substantial problem of delineating a clear data set in (Larkin 2013, 2014). It is sufficient to indicate here that the initial location of potentially useful apps is a time consuming and imprecise process and it is possible that some appropriate maths apps were therefore not reviewed. At the conclusion of the initial sorting process, there were 142 apps out of an initial pool of 4000, which were subjected to a full qualitative analysis in terms of their relevance to mathematics curricula, their appropriateness for primary school classrooms, and their ability to develop conceptual and procedural mathematical knowledge. Outcomes of this initial process are available at <http://tinyurl.com/ACARA-Apps>.

This chapter outlines the quantitative analysis of the 142 apps using the three quantitative measures indicated earlier. The decision to use these scales was made for several reasons. First, as there are currently no scales specifically designed for the evaluation of maths apps for iPads, scales used in other domains were modified for use in this research. Second, as all three scales have been used in related domains to evaluate software, they provide a mechanism for the later comparison of my findings to previous related research. Finally, as the Haugland Scale emphasises software design with students as the intended end users, and the Productive Pedagogies and Gee Learning Principles emphasise the potential learning afforded by the apps, their combined use provides a balanced review of the apps in terms of technical features, ease of use for students, and their ability to support mathematical learning.

Process One: Haugland Software Developmental Scale (1999)

The Haugland Software Developmental Scale (Haugland 1999)—henceforth referred to in this chapter as the Haugland Scale—is a criterion-based tool used to evaluate the appropriateness of web-based applications and software for use by children (Haugland 1999; Haugland and Ruiz 2002). The scale is based on ten criteria outlined in Table 1.

It is important to note that the Haugland Scale was not designed to evaluate mathematical apps. Consequently, two important modifications were made for this research. First, in order to analyse the data more thoroughly, the ten criteria were grouped into three sub-clusters (child centred, design, and learning). Second, elaborations were added to emphasise the relationship of the apps to mathematics. In scoring the apps, each of the ten criteria is worth one point and each app can thus score between 0 and 10. The scoring sheet includes a number of sub-indicators for each criterion. For apps to score a 1 for each criterion they must meet all relevant sub-indicators. If they meet 50 % or more of the indicators a score of 0.5 is recorded, and if less than 50 % are met, a score of 0 is recorded. For example, there are three sub-indicators in the Real-World Model criteria (concrete representation, objects function, simple reliable models). If an app demonstrated all three indicators a score of 1 was given, if two of the three indicators were demonstrated a score of 0.5 was given, and if one or none of the indicators were demonstrated a score of 0 was given.

Process Two: Productive Pedagogies

Productive Pedagogies (Atweh and Bland 2005) are criteria that teachers can use to critique their own practices in order to improve educational outcomes for their

Table 1 Adapted Haugland Developmental Software Scale (Haugland 1999) with clusters and elaborations

Cluster	Criteria	Criteria Elaboration with Links to Mathematics
Child Centred	Age Appropriate	The mathematics concepts taught by the app reflect realistic expectations for the age children for which it was designed.
	Child Control	When using the app, children decide the flow and direction for the experience, not the device. They are navigators, determining where the experience will lead, and learn the consequences of their choices.
	Independence	While adults may need to assist children in loading the application, after this initial guidance and support, children operate the app with minimal adult supervision.
	Non-Violence	Violence in apps is of particular concern because children often initiate and control the violence. In addition, the app models appropriate societal values.
Design	Clear Instructions	Verbal instructions are essential, since even children who are reading text-based instructions navigate with greater success if audio instructions are also provided. Directions are accompanied with visual prompts and/or a help option.
	Technical Features	The app is colourful with realistic uncluttered graphics, which enable children to focus on the learning objectives. Graphics are animated to help children attend. Whenever possible, children control the animation, learning mathematics through *hands-on* experiences.
	Real-World Model	The app provides children with concrete representations of objects found in meaningful and mathematically accurate situations or settings. The scale and colour of the objects are realistic, not stereotypical.
Learning	Expanding Complexity	The app is an exciting world that is easy for children to enter and reflects children's current cognitive, physical, mathematical and language skills. When children use the application a logical, mathematical learning sequence emerges.
	Process Orientation	Intrinsic motivation; the desire to explore and experiment and discover mathematics motivates children as they use the app, not rewards. The joy of learning is the reward in using the app.
	Transformations	Apps have the unique potential to give children opportunities to change objects and situations over and over, and discover how different mathematical components impact their world.

students. They are pluralistic in nature and do not prescribe a single model of pedagogical practice. There are 20 Productive Pedagogies grouped under four dimensions: intellectual quality, supportive classroom environment, connectedness, and recognition of difference (Education Queensland 2004). Although the Productive Pedagogies were designed for Queensland schools, they share much in common with international pedagogy standards such as those proposed by Newmann et al. (1995) to direct pedagogical change in Wisconsin schools. A number of pedagogies (substantive conversation, deep knowledge, connectedness to the real-world) are included in both the Queensland and Wisconsin pedagogies. Fifteen of the 20 Productive Pedagogies (Education Queensland 2004) were used in this research and the key question for each pedagogy was modified to make each relevant to mathematics (see Table 2).

Productive Pedagogies are not used to evaluate how the app might be utilised by a teacher in a teaching context. What is of interest is determining the effectiveness of maths apps in supporting student learning. Therefore, although the Productive Pedagogies refer largely to teaching, under investigation here is how the app encourages students to develop, for instance, deep thinking or self-regulation, or making connections to previous knowledge. Productive Pedagogies have been previously used in the work of Zevenbergen and Lerman (2007) who used them to investigate teacher and student use of interactive whiteboards.

Each of the 56 applications scoring more than 50% on the Haugland Scale was evaluated using the 15 Productive Pedagogies in Table 2. When evaluating the apps, if there was no evidence of the individual productive pedagogy, a score of 1 was recorded; if a high degree of evidence was present, a 5 was recorded. Consequently, the range of possible scores for the three dimensions was 30, 25 and 20 respectively and the overall range of scores was 15–75. As was the case with the Haugland Scale, Productive Pedagogies were not designed specifically for mathematics research, therefore modifications to the pedagogies were made, guided by the previous research design of Zevenbergen and Lerman (2007) and were also based on the initial qualitative review of the apps reported in Larkin (2013, 2014).

The first modification was to the key question associated with each of the pedagogies. For instance, in the student direction pedagogy, the initial key question did not include any reference to applications but only to students having a say in the direction or outcome of the learning activities. The more substantive change was the decision not to use the recognition of difference dimension. The recognition of difference dimension consists of five pedagogies: cultural knowledge, inclusivity, narrative, group identity, and citizenship. It became very obvious early in the review that the vast majority of apps were scoring very poorly in the recognition of difference dimension (mean score of 5.3/25). This dimension, therefore, did not add anything methodologically in comparisons among the three scales in judging an app's quality. I will articulate more fully, later in the chapter, why apps made minimal attempt to recognise difference.

Table 2 Productive Pedagogies and Key Questions (adapted from Classroom Observation Booklet by New Basics Branch and the Queensland School Reform Longitudinal Study [QSRLS] commissioned by Education Queensland)

Dimensions	Productive Pedagogy	Key Question
Intellectual Quality	Higher order thinking	Are students using higher order thinking operations while engaging with this app?
	Deep knowledge	Does the app cover mathematical content in any depth, detail or level of specificity?
	Deep understanding	Are the students required to demonstrate a deep understanding of concepts or ideas in completing activities associated with this app?
	Substantive conversation	Is there opportunity for dialogue between the student and the app in order to create or negotiate understanding of mathematics content?
	Knowledge as problematic	Are students critiquing ideas and knowledge presented via this app?
	Metalanguage	Are aspects of mathematics language being foregrounded in this app?
Supportive Environment	Student direction	Do students have any say in the pace, direction or outcome of the app?
	Social support	Does the app provide a supportive, positive learning context?
	Academic engagement	Does the app encourage student engagement and on-task behaviours?
	Explicit Quality Performance Criteria	Are criteria for student success in the app made explicit?
	Self-regulation	Is the direction of students' activity implicit and self-regulatory?
Connectedness	Knowledge integration	Does the app draw on knowledge from a range of mathematical domains?
	Background knowledge	Does the app scaffold early learning outcomes in the activity with those developed later in the activity?
	Connectedness to the world	Do activities within the app connect with students real-world mathematical experiences?
	Problem-based curriculum	Does the app encourage authentic mathematical problem solving and reasoning?

Process Three: Gee's Learning Principles (2003)

Gee (2003) established a set of 36 principles that underpin learning in digital environments. The use of Gee's work in reviewing digital games is based on the premise that "digital games are user-centred; they can promote challenges, co-operation, engagement, and the development of problem solving strategies" Gros (2007, p. 23). According to Jorgensen and Lowrie (2012), these 36 principles are drawn from three discourses (situated cognition, new literacy studies, and connectionism) and provide a "comprehensive account of the possibilities of games to create exciting and engaging learning opportunities" (p. 379). Table 3 indicates the ten learning principles selected for the evaluation of the apps and includes a modified definition for each.

For this research, the number of principles was reduced from 36 to ten for conceptual and methodological reasons. Based on the experience of the earlier evaluations, it was clear that many of the principles were not applicable for evaluating apps. For example, the self-knowledge principle indicates that learners learn about themselves in a virtual world. None of the apps develop virtual worlds and thus this principle is redundant. Also non-applicable, due to the already noted lack of concern with recognition of difference, were two principles related to cultural knowledge. In terms of methodology, it was considered a cumbersome process to use 36 principles in evaluating apps. In addition, previous research by Jorgensen and Lowrie (2011, 2012) indicated significant overlap on many of the principles. In determining the ten principles to use in this research, I was guided by the work of Jorgensen and Lowrie as well as my earlier qualitative experience of evaluating the apps.

Internal Reliability of the Three Quantitative Measures

In order to determine the reliability of the three quantitative measures used in this research, a Cronbach alpha–α was generated. The three individual α scores are presented in Table 4.

In social science research it is generally accepted that Cronbach alpha scores greater than 0.7 indicate a high degree of internal consistency (Muijs 2011). Briefly, Cronbach's alpha is concerned with the homogeneity of the items that make up the scale or how well the items hang together. In this particular case, we can view alpha in terms of the apps consistency of rating (be that high or low) across each of the domains (Haugland Criteria, Productive Pedagogies, and Gee's Learning Principles). From the data presented here, there is a high degree of confidence that the three scales are internally consistent, and thus we can be confident in their reliability to determine the quality of an app. I address issues of their validity in determining the quality of apps later in the chapter.

Table 3 Selected Learning Principles with modified definitions (Adapted from Gee 2003)

Principle	Modified Definition
Active, Critical Learning	All aspects of the app environment (including ways in which the semiotic domain is designed and presented) are set up to encourage active and critical, not passive, learning.
Semiotic	Learning about and coming to appreciate interrelations within and across multiple sign systems (e.g., images, words, actions, symbols, artefacts) as a complex system is core to the learning experience.
Achievement	For learners of all levels of skill there are intrinsic rewards from the beginning, customised to each learner's level, effort, and growing mastery, and signalling the learner's ongoing achievements.
Regime of Competence	The learner operates within, but at the outer edge, of his/her level of competence so that there is both safety and challenge.
Probing	Learning is a cycle of probing the world (doing something); reflecting in and on this action and, on this basis, forming a hypothesis; re-probing the world to test this hypothesis; and then accepting or rethinking the hypothesis.
Multiple Routes	There are many ways to complete the app, each of which caters for the strengths and interests of the learner.
Situated Meaning	The meanings of signs (e.g., words, actions, artefacts, symbols, texts) are situated in embodied experiences. Meanings are not general or decontextualised. Whatever generality meanings come to have is discovered bottom up via embodied experiences.
Practice	Learners get lots and lots of practice in a context where the practice is not boring (i.e., in an environment that is compelling to learners on their own terms and where the learners experience ongoing success). They spend lots of time on task.
Discovery	Overt telling is kept to a well-thought-out minimum, allowing ample opportunity for the learner to experiment and make discoveries.
Transfer	Learners are given ample opportunity to practice, and support for, transferring what they have learned earlier to later problems, including problems that require adapting and transforming that earlier learning.

Table 4 Cronbach alpha reliability scores for the three scales

Haugland Scale Reliability Scores

Case Processing Summary

		N	%
Cases	Valid	142	100.0
	Excluded[a]	0	.0
	Total	142	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.768	.765	10

Productive Pedagogies Scale Reliability Scores

Case Processing Summary

		N	%
Cases	Valid	56	100.0
	Excluded[a]	0	.0
	Total	56	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
.944	15

Gee's Learning Principles Reliability Scores

Case Processing Summary

		N	%
Cases	Valid	56	100.0
	Excluded[a]	0	.0
	Total	56	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.853	.853	10

The News Is…

The following section will briefly recap the findings from the qualitative review (as it contributes to the discussion of app quality) before examining in detail the findings from the various quantitative measures.

Qualitative Analysis

I have accounted for the qualitative review of the apps that are discussed here elsewhere (Larkin 2013, 2014). In this chapter, the focus is on considering the types of mathematical knowledge (Miller and Hudson 2007) developed by the apps. Conceptual knowledge involves a deep understanding related to the meaning of mathematics. Procedural knowledge is the ability to follow a set of sequential steps to solve a mathematical task. Declarative knowledge is information that students retrieve from memory without hesitation.

Table 5 is a summary of the number of apps supporting the development of conceptual, procedural, or declarative knowledge, or a combination of them. In percentage terms, 44.4% of the apps developed only declarative knowledge and

Table 5 Total number and percentage of apps developing differing forms of mathematics knowledge

Type of Knowledge	Number of Apps ($n=142$)	Percentage *(to nearest 0.1)*
Declarative	63	44.4
Procedural	42	29.6
Conceptual	12	9.9
Both conceptual and procedural	14	8.5
Both conceptual and declarative	2	1.4
Both procedural and declarative	7	4.9
All three knowledge types	2	1.4

52.1 % developed a combination of declarative and other types of knowledge. These percentages reflect findings in relation to iPod and iPhone mathematical apps (Kissane 2011; Pelton and Francis Pelton 2011). It is not suggested that declarative knowledge is of itself a negative as declarative knowledge provides an important foundation for procedural knowledge with the student accessing facts to complete a task (Bottge in Miller and Hudson 2007). What is suggested by the data is that declarative knowledge is overemphasised and that conceptual, and to a lesser degree, procedural knowledge is undervalued in mathematical apps. iPad software appears to be able to support manipulative devices and pictorial representations useful for conceptual development, and to provide sequential scaffolding for procedural mastery, yet most of the apps do not do so.

Quantitative Analysis

In order to get an overall sense of the data from the three scales, basic descriptive data on the three quantitative measures is provided in Table 6.

As an initial observation, a wide range of scores was recorded for each of the three measures. This clearly indicates that, even after the initial reduction of the

Table 6 Descriptive statistics of the three measures

Measure	Haugland Scale	Productive Pedagogies	Gee Learning Principles
N of Cases	142	56	56
Possible Total	10	75	50
Minimum	1	29	12
Maximum	10	71	45
Range	9	42	33
Mean	5	54.8	23.8
Std Deviation	1.99	10.64	7.40

4000 apps to just 142, and the subsequent further reduction of apps from 142 to 56, there is still a very wide discrepancy in the quality of the apps. It is not the case that there are only one or two high or low outliers in the data, as the large standard deviations for each of scales indicates that there was a consistent and large spread of quality across the app range. In terms of mean scores for each of the measures, it is evident that the apps scored most highly according to the Productive Pedagogies (73 %), attained a low pass mark on the Haugland Scale (50 %), and performed poorly on the Gee Learning Principles (43 %).

This initial statistical data supports the findings of the descriptive review where it was very clear that although there were some very strong apps, most were very poor quality. Once again, this comment takes into account only the 142 apps that were considered worthy of substantive examination and suggests that the vast majority of apps do not support the development of mathematical knowledge.

Process One: Haugland Scale

Table 7 indicates the top 20 apps according to the Haugland Scale; however, to indicate the results of all 142 apps, overall mean scores have been included.

The data indicates that the apps were strongest in the child-centred cluster (2.96/4) but weak in the other two clusters (design 1.35/3; learning 0.69/3). In terms of some of the individual criteria, the apps were quite strong on (independence 0.85/1; and non-violence 0.89/1) but extremely poor on (expanding complexity 0.25/1 and transformations 0.16/1). As the Haugland Scale is not specific to mathematics but designed to determine appropriateness of software for children, it was used in this research as a first cut measure of the apps. I took the research decision that if an app could not meet the three core demands of the Haugland Scale then the app was not appropriate to use. In essence, the Haugland Scale is very useful in weeding out the poor applications, and any app that did not score more than five was excluded from further investigation. Only 56 of the 142 apps initially evaluated using the Haugland Scale were considered appropriate for any further investigation. However, a score over 50 % does not in itself provide sufficient information for a decision to be made regarding the app's appropriateness in terms of developing mathematical knowledge. Consequently, two different quantitative measures were used to further evaluate the quality of the 56 remaining apps.

Process Two: Productive Pedagogies

The second quantitative evaluation procedure utilised 15 Productive Pedagogies. I have previously indicated that the recognition of difference dimension, with a mean score of 5.3/25, will not be used in further comparison of the apps. There are a number of reasons for the overall poor scores in this dimension. First, there is a global market for the apps and therefore any customisation for specific cultural

Table 7 Haugland Scale: Top 20 apps

Clusters on Haugland Scale	Child	Design	Learning	Total
Area of Rectangles	4	3	3	10
Miracle Learning for Calculation	4	2.5	3	9.5
Early Numbers: Maths Wizard Counting	3.5	2.5	3	9
Hands-on Equations—Lite	3.5	3	2.5	9
I See! Math 1	4	2.5	2.5	9
Mathemagica—Kids Math	4	2.5	2.5	9
Common Core Number	4	2	3	9
Adding Beads	4	2	2.5	8.5
Find and Count	4	2.5	2	8.5
Learn Numbers: Learn2Count	4	2.5	2	8.5
Math Dream	4	1.5	3	8.5
Maths Skill Builders—Primary	3.5	3	2	8.5
Fact Families—Add/Subtract	4	2	2	8
Friends of Ten	4	2.5	1.5	8
Hands-on Maths Attribute Blocks	4	2	2	8
Learn Math 1 (Mondiso)—Add/Subtract	4	2.5	1.5	8
Marble Math Junior	4	2.5	1.5	8
Time Math Free	3.5	2.5	2	8
123 Counting Fun Lite	4	2	1.5	7.5
Hands-On Maths Number Sense	3	2	2.5	7.5
Overall Mean for 142 apps	*2.96*	*1.35*	*0.69*	*5.01*

groups is problematic. Second, the lack of recognition of difference relates to the notion of *gamification*, discussed by Bossomaier (this volume) who suggests that in many cases, game-like elements are superficially added to digital resources in order for them to mimic games. For example, a rote learning app may be *gamified* by providing an opportunity for users to play a game if they score more than 18/20 in the maths tasks. Unfortunately, the *gamification* of the apps further minimises any potential recognition of difference as the rewards are generic in nature. Regardless of the exact reason, it is clear that most apps do not cater for diversity.

Table 8 provides summary data based on the three dimensions of intellectual quality, supportive environment, and connectedness. Although 56 apps were reviewed using these dimensions, data in this table reports only on apps scoring more than 37.5 (50 %).

An examination of the data provided in Table 8 indicates that 39 apps met the greater than 50 % criteria. The mean score for these apps was 49.2/75 (66 %). This percentage score was reasonably consistent across the three dimensions of intellectual quality (63 %), supportive environment (69 %), and connectedness (65 %). This again supports the claim made earlier that the Productive Pedagogies are internally consistent to a high degree. In terms of intellectual quality, three of the six criteria scored highly (deep knowledge 4/5, understanding 3.9/5, and metalanguage 3.7/5). The apps may have scored highly on these criteria because many apps are designed as knowledge generators, at least in terms of declarative knowledge, and to a lesser degree procedural knowledge. So the clear design intent of the apps was, for example, that students improve their multiplication facts or practice the division algorithm. In developing this type of knowledge, most of the apps used appropriate mathematical language and this accounts for the high score on the metalanguage criteria. In contrast, apps scored quite poorly on substantive conversation (1.4/5) and knowledge as problematic (2.2/5). Substantive conversation scores lowly by virtue of the fact that it is a substantial coding challenge for designers to cater for user interaction. The low score also relates to the overarching issue of diversity, and there is no acknowledgement in the apps that a conversation might be required with the user to better tailor the apps for their individual experience. The low score on the knowledge as problematic dimension correlates with low scores in the connectedness dimension and will therefore be discussed later in this analysis.

The apps score consistently across the supportive environment dimension with a mean score of close to 3.5/5 for four of the five criteria. This is not surprising as the apps are designed for independent use by young children, primarily in the home environment. Consequently, there are scaffolds in place to assist students in the design of the apps. The one dimension in this section, which scored slightly lower than the others, was self-regulation with a mean score of 3.1/5. This can be explained by the observation that self-regulation correlates with catering for individuals, and it has already been established that apps do not cater for this high degree of individuality.

There was a little more variation in the scores for the four criteria comprising the connectedness dimension. Two criteria scored well: connectedness to the real-world (3.7/5) and background knowledge (3.5/5); however the remaining two criteria scored poorly: knowledge integration (2.9/5) and problem-based learning (2.9/5). It

Table 8 Productive pedagogies results for apps scoring 50% or more overall

Productive Pedagogies Themes	IQ	SE	C	Total
Possible Maximum	*30*	*25*	*20*	*75*
Mathemagica	28	23	20	71
Area of Rectangles	28	22	16	66
Early Numbers: Maths Wizard Counting	24	22	14	60
Marble Math Junior	22	21	17	60
Miracle Learning for Calculation	24	23	12	59
Math Galaxy Fractions	21	21	17	59
Math Model	24	21	14	59
I See! Math 1	23	19	16	58
Find and Count	21	23	12	56
Common Core Number and Operations	21	19	16	56
Hands-on Maths Number Sense	23	18	15	56
Learn Numbers: Learn2Count	19	22	15	56
Hands-on Equations	20	20	14	54
Friends of Ten	20	19	14	53
Adding Beads	21	17	14	52
Learn Math 1 (Mondiso)	19	19	13	51
Statistics!!!	20	17	14	51
Math Dream	21	19	10	50
Maths Skill Builders—Primary	18	18	14	50
Fun Count App	19	17	12	48
Patterns, Colors and Shapes	17	17	14	48
123 Counting Fun	18	17	12	47
Fact Families—Add/Subtract	18	15	12	45

Table 8 (continued)

Productive Pedagogies Themes	IQ	SE	C	Total
Visual Math 1 & 2	18	14	12	44
Astromat Lite	16	18	9	43
Hands-on Maths Attribute Blocks	17	14	12	43
Math Grade 1	17	15	11	43
Middle School Math	17	15	11	43
Kindergarten Math	15	17	10	42
Base Ten Number blocks	18	13	10	41
Abby Adventure Winter Maths	13	17	10	40
Adventure Basic School Math	13	17	10	40
Column + - */	15	13	12	40
Number Skills	17	15	8	40
Red Dragonfly Mathematics Booklet	17	10	13	40
Telling Time HD	16	14	10	40
Time Math Free	14	14	12	40
Know Your Maths Facts Free	14	13	12	39
Probability Tools	16	9	14	39
Mean of apps scoring above 50%	*19.0*	*17.4*	*12.9*	*49.2*
Std Deviation	*3.7*	*3.5*	*2.5*	*8.5*

has already been established that apps are strong as declarative knowledge generators so it makes sense that the app designers take some cognisance of what children already know and build upon that throughout the apps by connecting with the real-world experience of the children (at least in a generic sense). The lack of knowledge integration and problem-based learning in the apps reflects the fact that most apps are designed as stand-alone apps targeting a particular type of knowledge or content area (e.g., adding common fractions, subtraction of two-digit numbers). There were very few apps that went deeper than this to connect different content areas in mathematics (e.g., common, decimal, percentage and proportional reasoning knowledge). This of course may relate to limitations with the available coding software on iPads. I suggest, however, it is more likely due to the desire of the designers to quickly develop and sell high volumes of a product in the one to two dollar range and the associated unwillingness to invest time and money into the development of a more substantive product for which there may be only a limited market. In summary, the findings from the Productive Pedagogies dimension review indicate that 12 of the 56 apps scored 75 % or higher overall and can be confidently recommended for use with primary-aged students. A further 11 apps scored between 60 % and 75 % overall and thus have some worth. The remaining 33 apps have only limited use in developing mathematical knowledge.

Process Three: Gee’s Learning Principles

The final quantitative measure used to evaluate the apps was the selected Gee’s Learning Principles, henceforth referred to as GLP, and only 24 of the 56 apps evaluated scored more than 50 % (see Table 9). In scoring the apps with this scale, each app could score from 1 (no evidence) to 5 (very strong evidence).

As was the case with the previous two scales, it is very clear that, according to GLP scores, there is a wide range in the quality of the apps. This applies across the 56 apps that were reviewed using these principles but is also evident in the 24 apps that scored more than 50 %. This again clearly indicates that there is a wide gulf between quality apps, however they are measured, and the majority of apps. The two principles that scored most highly across these 24 apps are the semiotic principle (mean score of 4/5) and the active learning principle (3.96/5). From the data already analysed using the Productive Pedagogies, this is not particularly surprising as the semiotic principle relates very closely to the metalanguage criteria, which scored highly. Likewise the observation of students being actively involved in their learning correlates with high scores on the academic engagement pedagogy as the apps are designed to support and encourage student learning.

The type of active learning evident in many apps is, however, different to that envisaged by Gee (2003) in the gaming environment context where the activity that users demonstrate is oriented towards a range of narrative goals. In many instances in using apps, student activity is solely related to completing a level in order to receive a non-related reward. In addition, the fact that the type of active learning

Table 9 Gee Learning Principles: Results for apps scoring 50 % or more overall

Gee Learning Principles	ACL	SEM	ACH	COMP	PROB	MULT R	SIT MEM	PRAC	DISC	TRANS	Total
Math Galaxy Fractions	5	5	4	5	4	5	4	4	4	5	45
Hands-On Maths Attribute Blocks	5	5	4	4	4	3	4	3	5	5	42
Area of Rectangles	5	5	3	3	4	3	3	3	4	4	37
Mathemagica	4	3	3	5	2	5	3	5	2	4	36
Marble Math Junior	4	4	4	4	3	4	3	3	3	2	34
Adding Beads	4	3	4	4	2	4	2	3	4	3	33
Maths Skill Builders	3	4	3	4	2	4	3	4	2	4	33
Friends of Ten	4	5	3	2	2	1	5	3	3	4	32
I See! Math 1	4	5	4	3	2	4	3	3	2	2	32
Miracle Learning for Calculation	4	5	3	4	2	2	3	4	3	2	32
Statistics!!!	5	5	2	4	2	4	2	2	2	4	32
Tens Frame	4	2	2	4	4	4	3	4	4	1	32
Math Dream	5	4	1	2	4	2	5	1	4	2	30
Hands-on Maths Number Sense	4	5	2	2	2	2	3	3	3	2	28
Probability Tools	4	2	1	2	5	1	3	1	5	4	28
Solids Elementary HD	5	3	1	1	4	3	3	1	5	2	28
Find and Count	4	4	2	2	1	2	5	3	3	1	27
Geometry 4 Kids	3	4	2	1	1	2	4	3	3	4	27
Middle School Math	3	3	3	2	2	4	1	4	3	2	27
Early Numbers: Wizard Counting	4	4	3	2	1	3	1	2	2	4	26
Toddler Counting 123	3	4	3	2	2	2	5	2	2	1	26
123 Counting Fun	3	4	3	2	1	3	2	3	2	2	25

Table 9 (continued)

Gee Learning Principles	ACL	SEM	ACH	COMP	PROB	MULT R	SIT MEM	PRAC	DISC	TRANS	Total
Math Grade One	3	4	3	2	2	4	2	1	3	1	25
Visual Math 1 & 2	3	4	3	3	2	2	3	2	2	1	25
Mean	*3.96*	*4.00*	*2.75*	*2.88*	*2.50*	*3.04*	*3.13*	*2.79*	*3.13*	*2.75*	*30.91*
Std Deviation	*0.75*	*0.93*	*0.94*	*1.19*	*1.18*	*1.16*	*1.15*	*1.10*	*1.03*	*1.36*	*5.25*

encouraged is mainly declarative knowledge, remains problematic. For example, in the Maths Alien app, the reward for passing a level is shooting alien ships, and in Monty's Quest the user gets to help a mouse push cheese up a hill as a reward for solving division problems. It is likewise unsurprising that the achievement principle (0.9/5), the probing principle (1.2/5), and the transfer principle (1.4/5) scored poorly. Higher scores can only be attained in these principles via a high level of customisation and the longer-term development of complex game narratives. Both of these dimensions are almost non-existent in apps. These scores mirror the findings of the knowledge integration and problem solving pedagogies, and again indicate that apps make little to no attempt to recognise any diversity in the end users.

A second point to consider is why so many of the apps failed to score more than 50% on the GLP. Firstly, and most obviously, the apps are not designed like games. The types of games that were reviewed in Gee's initial research, and also, to some degree, those used in the work of Jorgensen and Lowrie (2011, 2012), were full-featured video or digital games. These games had the opportunity to develop narratives and often offer multiple routes for solutions. Most apps are not designed in this fashion as their focus is *gamification* where, as indicated previously a simple rote learning activity is enhanced via the use of minor game elements. So the genre of many of the apps could be labelled *edutainment* where mathematics knowledge may develop as a consequence of students striving for the gameplay at the end of the task (see Nansen et al. 2012). The apps are also designed to promote *fun* learning and this facet is heavily promoted in marketing to parents. Finally, as indicated earlier, cost is a clear factor in the creation of these apps with the developers hoping for large sale volumes rather than making a serious investment into the creation of a quality game.

At the conclusion of the quantitative analyses, the question remains whether the failure of many apps to score highly according to GLP is an indication that the apps are poor, or an indication case that GLP is evaluating qualities that are not necessary in a quality mathematical app. An alternative hypothesis is that GLP are in fact evaluating quality in the apps; however, they are doing so using a stricter measure of quality than is the case with the Productive Pedagogies. Therefore, is it the case that both scales measure similar aspects of quality apps, with the GLP measuring that quality at a higher level of compliance than the Productive Pedagogies? The final contribution of this chapter is to determine whether the Productive Pedagogies and the GLP are both measuring similar quality in the apps, but are doing so in a different fashion. If the answer is "Yes" to this question, then teachers can use either of these measures and be confident in determining the quality of an app.

Correlation Analysis

In order to determine the correlation between the apps determined as being of high quality using the Productive Pedagogies and those determined using GLP, a Spearman's Ranked correlation on the two variables was performed. This data is presented in Table 10.

Table 10 Spearman’s Ranked correlation for Gee Learning Principles and Productive Pedagogies

	Gee Total	Intel Qual	Sup Envir	Connect	PP Total
Gee Total	1.000				
Intel Qual	0.602	1.000			
Sup Envir	0.415	0.783	1.000		
Connect	0.568	0.842	0.683	1.000	
PP Total	0.551	0.950	0.903	0.875	1.000

Table 11 Chi-square and *p* values for correlation

The Chi-square statistic is 10.3385. The P value is 0.001303. This result is significant at $p < 0.05$.

	PPHigh	PPLow
GeeHigh	21	9
GeeLow	7	19

Ma and Kishor (1997) suggest that correlations ranging from 0.20 to 0.40 can be considered practically meaningful in behavioural sciences and indicate that “a correlation of 0.30 is actually equivalent to an increase of 30 % in the success rate of an intervention” (p. 27). The correlation coefficient (rho) between the variables shown in Table 10 indicate a moderate positive correlation between the Productive Pedagogies and GLP scores overall, and very high correlations between the three Productive Pedagogies dimensions. This is not surprising given the high Cronbach alpha scores reported earlier. The correlation analysis suggests that although the scales are determining quality using different criteria, both scales are delineating similar apps as being of high quality. This is significant as it answers “Yes” to the question posed earlier, inferring that teachers can be confident in using either measure to assist them in determining the quality of an app.

In terms of this particular research, given that I have measured the apps using both scales, it is reasonable to conclude that the combined distance from the median scores on Productive Pedagogies and GLP will provide a very accurate measure of the quality of the apps reviewed. Table 11 indicates the location of the 56 apps according to a measure of distance from the median score using a Chi-square measure.

It is evident from Table 11 that of the 56 apps evaluated, 21 scored above the median scores in both Productive Pedagogies and GLP; 7 were above on Productive Pedagogies but below on GLP; 9 were below on Productive Pedagogies but above on GLP; and 19 were below on both measures. There were other apps which scored above the median overall; however, these were not included as they scored below the median in one of the two individual measures. Table 12 provides further information on the 21 apps that scored above median values for both measures.

Based on this median data, I am confident in reporting that any of the apps listed in Table 12 are very useful in assisting students to develop mathematical knowledge in primary school contexts. In addition, although the Productive Pedagogies dimensions are more closely related to school classrooms and therefore easier to use

Table 12 Median scores for Productive Pedagogies & Gee and overall combined median score

Apps	PP TOTAL	Median	Median Dev	High Low	Gee TOTAL	Median	Median Dev	High Low	Med Dev Sum
Mathemagica	71	42.50	28.50	1	36	22	14	1	42.50
Math Galaxy Fractions	59	42.50	16.50	1	45	22	23	1	39.50
Area of Rectangles	66	42.50	23.50	1	37	22	15	1	38.50
Marble Math Junior	60	42.50	17.50	1	34	22	12	1	29.50
Miracle Learning for Calculation	59	42.50	16.50	1	32	22	10	1	26.50
I See! Math 1	58	42.50	15.50	1	32	22	10	1	25.50
Early Numbers: Maths Wizard	60	42.50	17.50	1	26	22	4	1	21.50
Friends of Ten	53	42.50	10.50	1	32	22	10	1	20.50
Adding Beads	52	42.50	9.50	1	33	22	11	1	20.50
Hands-on Maths Attribute Blocks	43	42.50	0.50	1	42	22	20	1	20.50
Hands-on Maths Number Sense	56	42.50	13.50	1	28	22	6	1	19.50
Find and Count	56	42.50	13.50	1	27	22	5	1	18.50
Statistics!!!	51	42.50	8.50	1	32	22	10	1	18.50
Maths Skill Builders	50	42.50	7.50	1	33	22	11	1	18.50
Math Model	59	42.50	16.50	1	23	22	1	1	17.50
Learn Numbers: Learn2Count	56	42.50	13.50	1	24	22	2	1	15.50
Math Dream	50	42.50	7.50	1	30	22	8	1	15.50
Hands-on Equations	54	42.50	11.50	1	22	22	0	1	11.50
123 Counting Fun	47	42.50	4.50	1	25	22	3	1	7.50
Middle School Math	43	42.50	0.50	0	27	22	5	1	5.50
Visual Math 1 & 2	44	42.50	1.50	0	25	22	3	1	4.50

for teachers, either measure will determine an app's quality. The apps scored more highly on the Productive Pedagogies, perhaps because this measure is designed for more formal educational contexts. In addition, the apps are not designed as video games, but rather as small-scale, content-specific learning applications and thus have not scored as well on a scale designed to evaluate video games.

So Do Apps Cut the Mustard?

The process outlined in this chapter has established that there is a large discrepancy in the quality of apps available at the App Store, with many of limited to no use at all in terms of mathematical learning. However, I do not wish to be a 'prophet of doom' in relation to their use by children. Despite the fact that many apps are marketed with glib promises of accelerating student learning or making learning fun, and the observation that many apps clearly do not meet the criteria of *serious* digital games as suggested by Bossomaier (this volume) and Beavis (this volume), the apps listed in Table 12 certainly do 'cut the mustard' and are highly innovative in terms of supporting mathematical knowledge. The three tools used for moderating the quality of the apps have shown that there is high intellectual quality in the final cut of the apps. This process has highlighted the potential of these apps to promote deep learning across a number of areas in mathematics.

Three apps in particular, as evidenced by the median scores, are clearly exceptional. Mathemagica is an innovative application, using a range of digital images and sounds, to provide an engaging experience for students in developing a diverse range of concepts including Number, Place value, the null property, and order of operations. Although a different style of app, Area of Rectangles combines a range of activities, utilising similar technology evident in full-scale virtual manipulatives websites such as Illuminations or the National Library of Virtual Manipulatives (NLVM) to develop conceptual, procedural, and declarative knowledge. Finally, Maths Galaxy Fun uses a range of pictorial representations to develop conceptual understanding of fractions. In addition, students can complete a range of step-by-step tutorials and thus be in control of their learning. What these apps demonstrate is that the iPad, as a technological tool, is a capable platform for the delivery of quality mathematical apps for primary-aged children. Given this, and pending future confirmation by classroom teachers and students, I am confident at this stage to answer "Yes" to the implied question rhetorically posed in the title. There are apps currently available that support the development of mathematical knowledge. What is critical in terms of the plethora of apps that are on the market is that caution and care must be enacted if quality learning (as opposed to rote activities) is the desired outcome. The quantitative measures described and implemented in this paper have shown that there are means by which educators are able to discern quality apps for mathematics learning.

What is of greater concern, given the vast number of available apps, is the issue of how teachers, under significant time pressures, can accurately determine whether an application will develop the type of deep learning evidenced in the selection of apps recommended in Table 12. I have argued in this chapter and elsewhere that teachers cannot rely solely on information from the iTunes store. Qualitative reviews of apps—such as the one I conducted in 2013, or those available at a range of educational websites—are useful but limited by a number of factors, e.g., assessor subjectivity, range of access to apps, and most significantly, the reviews become quickly dated as existing apps are deleted or updated and new apps become available. The quantitative measures utilised in this research bring a high degree of academic rigour to the evaluation of apps. With a high degree of confidence, the data indicate that an app scoring highly on either measure is indeed a quality app capable of supporting deep learning. The measures are internally consistent, relatively simple to use, assess the types of knowledge that teachers expect their students to develop, and more objective than current qualitative measures, and the determination of quality is more easily communicated to colleagues via numerical scores.

This chapter has demonstrated that the use of Productive Pedagogies and Gee's Learning Principles, either together or independently, given the degree of positive correlation, is a means by which teachers (educators or even parents) can confidently identify whether or not an app will support deep, connected learning beyond the normal confines of formal schooling. This is a fundamental and profound shift in approach to the evaluation of apps. Until now, rigorous quantitative measures for evaluating apps have been unavailable, and teachers have been obliged to rely on largely anecdotal and often prejudiced accounts of educational quality. Using the measures proposed in this chapter positions teachers as educational leaders, confident in selecting and using apps with their students that will enhance deep and connected learning. This confidence, when communicated to colleagues, will encourage those who may have been reluctant to use iPad apps in their mathematical practice, to likewise engage with the technology and thus offer an enhanced range of learning opportunities for their students. The use of the quantitative measures designed in this research is a substantive contribution to overcoming the difficult problem of sorting the "wheat from the chaff" in terms of mathematical apps.

This chapter has reported on the process by which the author evaluated a range of mathematical apps. The next phase of the research is currently underway and involves groups of teachers, at a range of schools, using the quantitative measures to evaluate apps. This process will assist in the fine-tuning of the evaluative measures discussed in this chapter and will also enhance the quality of the current reviews available to classroom practitioners. Future research will then involve the use of some of the recommended apps with primary school students to begin to measure the impact of app use on student learning.

Acknowledgements I would like to acknowledge the contribution of Dr. Todd Milford with some of the data analysis presented in this chapter.

References

Attard, C., & Northcote, M. (2011). Teaching with technology: mathematics on the move: using mobile technologies to support student learning (Part 1). *Australian Primary Mathematics Classroom, 16*(4), 29–31.

Atweh, B., & Bland, D. (2005). Mathematics through/for understanding social life: Productive pedagogies meets critical mathematics. Paper presented at the *Mathematic Education and Society Proceedings of the 4th International Conference*. Brisbane.

Clements, D. H., & Sarama, J. (2007). Effects of a preschool mathematics curriculum: Summative research on the building blocks project. *Journal for Research in Mathematics Education, 38*(2), 136–163.

Education Queensland. (2004). *Productive pedagogies: Classroom reflection manual* [website]. State of Queensland (Department of Education). http://education.qld.gov.au/public_media/reports/curriculum-framework/productive-pedagogies/.html. Accessed 21 Dec 2012.

Gee, J. P. (2003). *What video games have to teach us about learning and literacy*. New York: Palgrave Macmillan.

Goodwin, K., & Highfield, K. (2013). A framework for examining technologies and early mathematics learning. In L. D. English & J. T. Mulligan (Eds.), *Reconceptualizing early mathematics learning advances in mathematics education* (pp. 205–226). Netherlands: Springer.

Gros, B. (2007). Digital games in education: The design of games-based learning environments. *Journal of Research on Technology in Education, 40*(1), 23–38.

Haugland, S. (1999). Computers and young children: The newest software that meets the developmental needs of young children. *Early Childhood Education Journal, 26*(4), 245–254.

Haugland, S. W., & Ruiz, E. A. (2002). Empowering children with technology: Outstanding developmental software for 2002. *Early Childhood Education Journal, 30*(2), 125–132.

Jonas-Dwyer, D. R. D., Clark, C., Celenza, A., & Siddiqui, Z. S. (2012). Evaluating apps for learning and teaching. *International Journal of Emerging Technologies in Learning, 7*(1), 54–57. doi:10.3991/ijet.v7i1.1901.

Jorgensen, R., & Lowrie, T. (2011). Digital games: Creating new opportunities for mathematics learning. Paper presented at the *Mathematics: Traditions and [New] Practices* (Proceedings of the 34th annual conference of the Mathematics Education Research Group of Australasia and the Australian Association of Mathematics Teachers). Alice Springs.

Jorgensen, R., & Lowrie, T. (2012). Digital games for learning mathematics: Possibilities and limitations. In J. Dindyal, L. P. Cheng, & S. F. Ng (Eds.), *Mathematics education: Expanding horizons* (Proceedings of the 35th annual conference of the Mathematics Education Research Group of Australasia, pp. 378–384). Singapore: MERGA.

Kissane, B. (2011). Mathematics education and the iPod touch. Paper presented at the *Mathematics: Traditions and [New] Practices*. (Proceedings of the 34th annual conference of the Mathematics Education Research Group of Australasia) and the Australian Association of Mathematics Teachers). Alice Springs.

Larkin, K. (2013). Mathematics education. Is there an app for that? Paper presented at the *Mathematics Education: Yesterday, Today and Tomorrow* (Proceedings of the 36th annual conference of the Mathematics Education Research Group of Australasia). Melbourne: MERGA.

Larkin, K. (2014). Ipad Apps that promote mathematical knowledge? Yes, they exist! *Australian Primary Mathematics Classroom, 19*(2), 28–32.

Leong, Y. H., & Chick, H. L. (2011). Time pressure and instructional choices when teaching mathematics. *Mathematics Education Research Journal, 23*(3), 347–362. doi:I0.I007/s13394-011-0019-y.

Ma, X., & Kishor, N. (1997). Assessing the relationship between attitude toward mathematics and achievement in mathematics: A meta-analysis. *Journal for Research in Mathematics Education, 28*(1), 26–47. doi:10.2307/749662.

McManis, L. D., & Gunnewig, S. B. (2012). Finding the education in educational technology with early learners. *Young Children, 67*(3), 14–24.

Miller, S. P., & Hudson, P. J. (2007). Using evidence-based practices to build mathematics competence related to conceptual, procedural, and declarative knowledge. *Learning Disabilities Research & Practice, 22*(1), 47–57.

Muijs, D. (2011). *Doing quantitative research in education with SPSS* (2nd ed.). London: Sage.

Nansen, B., Chakraborty, K., Gibbs, L., Vetere, F., & MacDougall, C. (2012). 'You do the math': Mathletics and the play of online learning. *New Media & Society, 14*(7), 1216–1235. doi:10.1177/1461444812442926.

Newmann, F., Marks, H., & Gamoran, A. (1995). Authentic pedagogy: Standards that boost student performance. *Center on Organization and Restructuring of Schools*. Madison, Wisconsin.

Ntuli, E., & Kyei-Blankson, L. (2011). Teacher criteria for evaluating and selecting developmentally appropriate computer software. *Journal of Educational Multimedia and Hypermedia, 20*(2), 179–193, 1–52.

Pelton, T., & Francis Pelton, L. (2011). Design principles for making meaningful mathematics apps. Paper presented at the *Proceedings of Society for Information Technology & Teacher Education International Conference 2011*. Chesapeake.

Pelton, T., & Francis Pelton, L. (2012). Building mobile apps to support sense-making in mathematics. Paper presented at the *Proceedings of Society for Information Technology & Teacher Education International Conference 2012*. Chesapeake.

Polly, D. (2011). Examining how the enactment of TPACK varies across grade levels in mathematics. *Journal of Computers in Mathematics and Science Teaching, 30*(1), 37–59.

Potter, J., Johanson, J., & Hutinger, P. (n.d.). *Creative software can extend children's expressiveness*. http://www.wiu.edu/users/mimacp/wiu/articles/software4.html. Accessed 12 Dec 2012.

Scanlon, M., Buckingham, D., & Burn, A. (2005). Motivating maths? Digital games and mathematical learning. *Technology, Pedagogy and Education, 14*(1), 127–140.

Shuler, C., Levine, Z., & Ree, J. (2012). *iLearn II: An analysis of the education category of apple's app store*. New York: The Joan Ganz Cooney Center at Sesame Workshop.

Yuan, T., Chae, H. S., Nantwi, G., & Garg, P. (2010). An Examination of 300 iPhone Math Applications: Implications for the Development of an Educational Math Game. Paper presented at the *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications*. Chesapeake: AACE.

Zevenbergen, R., & Lerman, S. (2007). Pedagogy and interactive whiteboards: Using an activity theory approach to understand tensions in practice. *Mathematics: Essential Research, Essential Practice, 2,* 853–862.

Kevin Larkin is a Lecturer in Mathematics Education in the School of Education and Professional Studies at Griffith University in Australia. Kevin's research interests and expertise include student attitudes to mathematics in primary school, the experience of transition into high school and its implications for mathematics education, mathematics education for pre-service teachers in blended and online contexts, and the nexus between digital technologies and mathematics education. He is involved in four different research teams investigating these research interests, including the AU$3.2 million research project funded by the Office for Learning and Teaching, *Step up! Transforming Mathematics and Science Pre-service Secondary Teacher Education in Queensland*.

Digital Games and Mathematics Learning: The State of Play

Tracy Logan and Kim Woodland

Abstract This chapter examines the spread and involvement of digital games in mathematics learning over the last 5 years (from 2009 to 2013) in English-speaking countries. It examines the patterns and trends that are emerging in an industry that has increasing social influence. This chapter is less about the advantages and disadvantages of digital games and their impact on mathematics learning, and more about present influences and trends—that is, what is actually happening in the world of digital games? What is trending? What technology is being taken up? Are teachers actually using digital games to enhance learning in the classroom, and if so, how? The chapter will become an historical transcript quite quickly, and thus will serve as a reference point for future trends and innovations.

Keywords Web content analysis · Gaming industry trends · Game-based learning · Edu-versioning · Knowledge Discovery in Data (KDD)

Introduction

To examine the state of play in digital games over the last 5 years is to attempt to provide a static commentary on an ever-changing industry. The multibillion dollar digital games industry looks dramatically different now than it did even 5 years ago. And it will be different again in 5 years' time, with the continued emergence and obsolescence of games and gaming devices as the market and technology interact and innovate.

Not only is the digital games industry continually changing, however, its relationship to education—in particular to mathematics learning—is ambiguous. In

T. Logan (✉)
Faculty of Education, Science, Technology and Mathematics, University of Canberra, Canberra, Australia
e-mail: tracy.logan@canberra.edu.au

K. Woodland
Research Institute for Professional Practice, Learning and Education, Charles Sturt University, Wagga Wagga, Australia
e-mail: kwoodland@csu.edu.au

© Springer Science+Business Media Dordrecht 2015
T. Lowrie, R. Jorgensen (Zevenbergen) (eds.), *Digital Games and Mathematics Learning,* Mathematics Education in the Digital Era 4, DOI 10.1007/978-94-017-9517-3_14

researching the connection, it quickly becomes apparent that the interaction between digital games and education is not precise. Games are not solely *educational* or *commercial* and they are used both inside and outside of traditional learning environments. In fact, the popularity of digital games means that educators using them in the classroom to facilitate learning are working with a resource that students may have greater expertise with, not to mention one that has previously been banned from classrooms as a distraction.

Nevertheless, it is important that an attempt is made in a volume such as this to define the current state of play in digital games. This is not to provide information that will be outdated within a short period of time (although it will be), but to acknowledge that digital games and gaming is now a central feature in society—and increasingly so in the field of education. Over time, the industry, the devices used to game, the games themselves, and the way people game will change, however the infiltration of digital games into education is likely to remain strong in the foreseeable future.

In early 2010, game designer Jane McGonigal gave a talk at a TED conference on how gaming can make a better world. As of early 2014, her talk had received almost 3.4 million views. She referred to the "parallel track of education" experienced by the average youth living in a country with a strong gaming culture: 10,000 h spent in online gaming by age 21, which is about the same number of hours spent in middle and high school with perfect attendance. The reason that games are so enticing, McGonigal contends, is that they provide "satisfying work, real hope for success, strong social connections and the chance to become a part of something bigger than ourselves" (McGonigal 2011). She would like to see the considerable skills developed by gamers applied to real-world problems and argues that bringing issues into the gaming environment for solution provides the right environment for problem solving.

> In the best-designed games, our human experience is optimized: We have important work to do, we're surrounded by potential collaborators, and we learn quickly and in a low-risk environment. (McGonigal 2010, n.p.)

Jorgensen (Zevenbergen) (this volume) also identifies the social dimensions of gameplay as it relates to students from varying backgrounds and how the environment created by games provides opportunities to influence learning.

As cases describing the state of play in digital games are identified throughout the chapter, information will be presented in three major areas: the state of the digital games industry; the societal and political forces influencing digital gaming; and the reaction within the field of education.

Research Overview and Process

In order to better understand the state of play, we undertook a data mining process to focus on the relevant information. Hand (1998) defined data mining as "the process of secondary analysis of large databases aimed at finding unsuspecting relationships which are of interest or value" (p. 112). One of the largest and most accessible data sources is the World Wide Web. To this end, this chapter does not seek to describe patterns and relationships regarding quantifiable counts or measures. Rather, it undertakes the analysis process through a lens that is a bounded description of what information was available in a specific parameter of time. It would be fruitless to highlight quantifiable counts when the nature of the World Wide Web dictates that any static measure is redundant within a minute. As a consequence, the analysis undertaken in this chapter captures the interconnectivity of themes and reports unsuspecting relationships within the context of digital games.

Knowledge Discovery in Data (KDD) (Fayyad et al. 1996) is a model that provided opportunities to explore the rapidly growing proliferation of digital data through the extraction of useable knowledge from a collection of data. For the purposes of this chapter, this model provided a clear process to follow as we examined the increase of digital games into the education sector. The process is both interactive and generative and involves a series of sequential steps and corresponding decision-making processes (Fayyad et al. 1996). Figure 1 provides an overview of the KDD process.

According to Fayyad et al. (1996), there are five steps in the KDD process. The *Selection* step involves selecting data from the larger database to create a target data set. The target data set is based on the goals of the project and the relevant prior knowledge of the data, i.e., focusing on a subset or a sample of data. *Preprocessing* involves reducing the target data set to the useful features that represent the goals of the project, essentially sorting and organising the data. Preprocessing requires the researcher to look at the data in a manner that allows them to make decisions about the exact nature of analysis. *Transformation* of the data requires a suitable analysis technique to be identified based on the goals of the project and the type of data being utilised. Data can be transformed through any analysis technique, with the aim to classify, cluster and summarise the data. *Data mining* is seen as searching for and "determining patterns from observed data" (Fayyad et al. 1996, p. 43). This step can often involve a form of visual representation of the extracted patterns. The

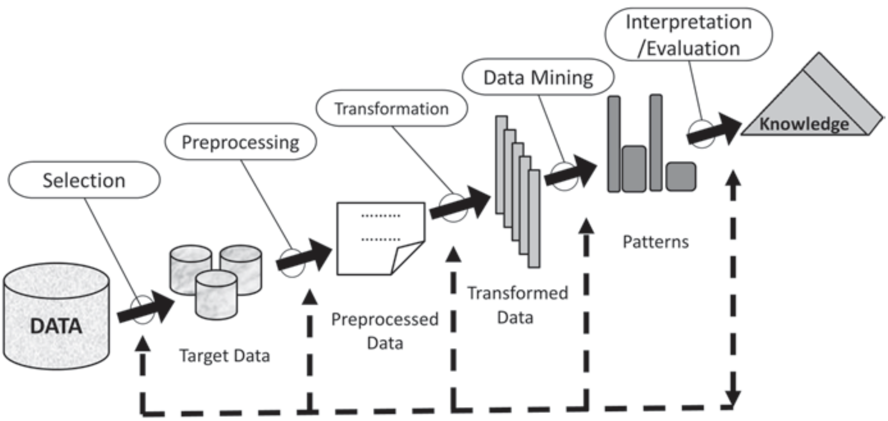


Fig. 1 An overview of the KDD process (Adapted from Fayyad et al. 1996, p. 41)

Interpretation/Evaluation step consists of interpreting any patterns and themes identified in the data mining step in relation to the project goals and evaluating their usefulness and potential interest to others. This chapter followed these steps and they are explained in the sections below with specific reference to this book's context. The Interpretation/Evaluation section of this chapter will follow our data presentation.

Selection of the Data

The selection step required the authors to identify the essential data from the original data set (World Wide Web). This initial step consisted of identifying clear search boundaries that were directly related to the goals of the book. Hence, the subset of data was identified in three ways. First, the data was limited to information found on the English language search engine Google (which also included data on some countries covered in this book, such as Brazil, where English-language information was included in the search results). This included sources from:

- Blogs and wikis
- Publishers' websites
- Books
- Magazines
- Conferences
- Government funding
- YouTube
- Research institutes and organisations focused on research into digital games
- Twitter (#digitalgames)

Second, we concentrated less on academic sources and more on sources readily accessible to teachers. We adopted this wide-reaching view because digital gaming (and especially the link with education) is still an under-researched subject in academia. As Calder points out (this volume), the speed at which technology is moving has outpaced the research that could "inform and validate" the use of digital technologies and gaming in learning environments.

Third, the following search terms were utilised:

- Digital games
- Digital games in classrooms
- Digital game-based learning
- Digital games in mathematics education
- Gamification

Such search parameters produced many results. For example, a search on Google Blogs for "digital game-based learning" produced over 1.5 million results. The same search terms used on Google Web produced 116 million results. Although this confirmed our belief that the digital games industry and games in the education sector are popular and varied, we also recognised that our data needed to be further refined for analysis.

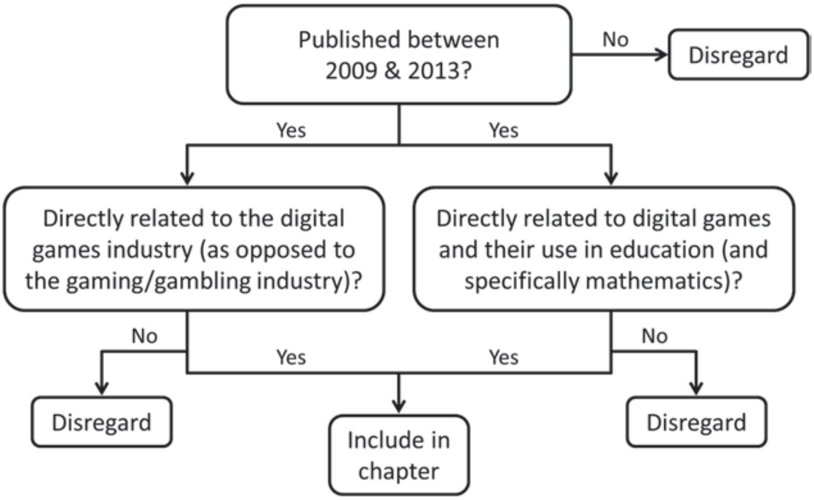


Fig. 2 Flowchart illustrating the winnowing process for acquiring data

Preprocessing/Organising the Data

The preprocessing step involved organising the data for analysis. This included using data reduction techniques and "finding useful features to represent the data depending on the goals of the task" (Fayyad et al. 1996, p. 42). This step involved clarifying our focus for this chapter and the book. The flowchart in Fig. 2 was used to reduce the data to manageable terms. Questions were asked of the data in relation to the time it was published online and the relationship to the digital games industry and digital games in education.

To this end, our data reduction identified two distinct categories, namely: the state of the digital games *industry* and the state of digital games *in education*. These two categories were utilised throughout the next two steps in the model.

Transformation of the Data

Transformation of the data involves identifying an analysis technique that will classify, categorise and summarise the target data with respect to the aims of the project. For this chapter, the authors utilised a Web Content Analysis (WebCA) (Herring 2010; McMillan 2000). The WebCA was conducted under the parameters of the KDD model described and was undertaken during a 1-month period in January 2014.

According to Payne and Payne (2004), "Content Analysis seeks to demonstrate the meaning of written or visual sources…by systematically allocating their content to predetermined, detailed categories,…and interpreting the outcomes" (p. 51). In contrast to traditional content analysis, the authors did not wish to undertake statistical procedures on the results and so data utilised in the analysis were not quantified through frequencies and counts. Instead, the authors sought to explain a distinct phenomenon at a particular time, within a specific field of enquiry, with the aim of explaining particular contexts and events. As Best and Khan (2006) suggest, this type of content analysis can aid "in yielding information helpful in evaluating or explaining social or educational practices" (p. 258).

Data Mining

Data mining is the fourth step in KDD and is seen as "searching for and determining patterns from observed data" (Fayyad et al. 1996, p. 43). The observed data in this study are taken from the web content analysis with consideration of the two identified categories. As such, our data mining attempted to draw meaning from these data by identifying repetitive themes and illustrative cases. This included: examining statistics from the gaming industry to consider scope and depth of the games being purchased and played, as well as changes that have occurred over the last 5 years and potential differences between countries; funding opportunities that have arisen in the digital gaming industry and for the use of digital games in education; conferences that are taking place globally with respect to digital games; books that are being published in the field; resources that educators may look to; and the impact on education.

The following sections present our findings in relation to the games industry and the impact of games in the field of education.

The State of the Digital Games Industry

Digital games are a growing multibillion dollar worldwide industry. Within the global digital content market, digital games are the biggest content category (ahead of digital movies and music)—with apps the strongest driver of growth (IHS Technology and App Annie 2014). In 2013, the sale of digital games in Western markets (including Canada, United States of America [USA], Brazil, Germany, France, United Kingdom [UK], Italy, Spain and Poland) reached US$21.8 billion (SuperData 2013d). The USA alone comprised US$11.8 billion of this market, up 11 % from the previous year (SuperData 2014a).

While the USA is the largest digital games market in the world, one of the fastest growing is the Latin American country Brazil, where the rate of Internet penetration is 18 % higher than the worldwide average (SuperData 2013c). Here, the online games market sold US$1.4 billion in 2013 and is forecast to reach US$2.4 billion by 2015 (SuperData 2013c)—an increase of over 40 % in just 2 years.

Early in the 5-year period examined by this chapter, Divide by Zero Games CEO, James Portnow (2010), delved into the under-researched games market in Brazil and found a country with great potential for gaming (an interested demographic along with growing wealth, education levels and access to the Internet), but also with serious constraints (a high tax rate on games, piracy and a limited distribution network). Portnow described Brazil as having "infinite possibility" for game development, including within education:

> The Brazilian government has been active in subsidizing, assisting, and incentivizing the creation of educational games. As a result, the edutainment products coming out of Brazil are, in my opinion, superior to what I've seen come out of the US. (n.p.)

Since Portnow published his blog post, the upward trend in Brazil's digital games market has continued. When digital goods measurement company, SuperData (2013c) released their 2013 report on the industry in Brazil, they found that increased access to the Internet had rapidly boosted the sale of online games, and the proliferation of smartphones led to mobile games comprising 40 % of total games revenue in the country. As physical games attracted a higher rate of tax, they made up a much smaller portion of the market; consoles comprised only 5 % of sales (SuperData 2013c).

In another 2013 report on the state of the computer and video games industry, the USA-based Entertainment Software Association (ESA 2013) gathered data from over 2000 nationally representative American households during 2012. They reported on the use of digital games within the average household. Their results show that most homes in the USA contain at least one dedicated game console, PC or smartphone; the average age of gamers is 30 (the split is fairly even across age groups—32 % are under 18 years, 32 % are 18–35, and 36 % are 36 or older); and slightly more males than females are gamers (55 % male and 45 % female).

These data have varied somewhat since 2009. Back then, the average gamer was slightly older—at 34 rather than 30, with the younger and older markets comprising a smaller percentage of gamers who were dominated by 18–49-year-olds (49 %). Only 25 % were under 18 years of age (compared with 32 % in 2012). The gender split was more in favour of gaming males in 2009 (60 % male, 40 % female), but has since evened, although still slightly more men than women identify as gamers (ESA 2010, pp. 2–3). Other research confirms changes in demographics, including the continued expansion of gaming into the younger (and older) age groups. Says Levine and Vaala (2013):

> Children as young as 4 years old have increasingly sophisticated digital lives, and 10-year-olds partake in more than 7 hours of media consumption a day—almost an hour and a quarter of which is used to play digital games! (p. 72)

The ESA also delved into the reasons why gamers choose to play particular games: high-scoring preferences included the quality of game graphics, an interesting storyline, a sequel to a favourite game and word of mouth (ESA 2013, pp. 2–3). These consumer preferences frame both game design and the marketing and merchandise contained in the overall *packaged* experience.

Trends in Devices

In this section, we provide an overview of the major trends in the devices being used. By the term *devices*, we refer to those hardware tools that are used to play the game—both fixed hardware and mobile devices. Advances in technology, and especially the capacity to have large amounts of processing memory stored in small hard drives, have resulted in the emergence of a number of new devices in recent years.

Presently, games are played on a range of devices, including:

- personal computers (PCs);
- consoles (such as the Microsoft Xbox, Nintendo Wii or Sony PlayStation);
- handheld gaming devices (such as Nintendo's DS or 3DS, or Sony's Vita—Microsoft does not have one, opting to use its Windows smartphone as its mobile games platform);
- smartphones; and
- tablets.

The majority of games sold during 2013 in Western markets were played on PC/online (51 %), while the remainder were played on consoles (30 %), mobile devices (smartphones and tablets) (14 %), and only 5 % on handheld gaming devices (SuperData 2013d). Nevertheless, the segments of the market are shifting—with not only advances in technology, but demand from gamers and new offerings from manufacturers and game designers dictating what devices games will be played on. Digital technology is revolutionising gaming, just as it is doing with media, music and movies. The dominant PC/online platform is currently under threat from mobile technology. As a result, many of the "leading PC online games companies…are focusing investments on mobile for future growth and overseas expansion" (IHS Technology and App Annie 2014, p. 14). And only 5 years ago (in 2008), when mobile gaming was in its infancy, consoles were the device of choice for over 40 % of gamers (SuperData 2013b)—beating out PC/online. A major reason that the traditional physical gaming market sold through retail outlets (often referred to as the *video games* market and including consoles and handheld gaming devices) is declining is that players are opting for devices that can be used for a range of purposes, such as smartphones, tablets and PCs.

In Australia, for example, the sale of traditional physical games fell 23 % during 2012 as customers continued to switch to digital games such as apps and PC downloads (Moses 2013). And in Brazil, the relative cheapness and easier access to online and mobile games meant their recent sales far outstripped those of traditional physical games sold through retail outlets (SuperData 2013c)—both increasing the size of the gaming market while simultaneously helping to combat piracy.

As well as gaming, people also use their devices for the following purposes: 42 % also watch movies; 22 % listen to music; 19 % watch television shows; and 5 % watch live content (ESA 2014, p. 5). This data on multipurpose devices was not even a category in the ESA's report on the market in 2009. Such trends indicate that games will be played on small devices (in terms of screen size) and are likely to be embedded within other multitasking applications in the immediate future.

The world's largest gaming companies are innovating to keep pace with the trend toward multiuse devices—particularly the big three who specialise in consoles or handheld gaming devices: Microsoft, Nintendo and Sony. At the 2013 Consumer Electronic Show in Las Vegas, "Microsoft Xbox reaffirmed its strategy to make its console a multipurpose device… the idea that a console is a single-purpose device is the past. The future is a multitasking customer—a device that does more than just gaming at home" (SuperData 2014a, n.p.). At the same show, Sony announced it would adapt its traditional strength—console gaming—and expand its offering by "developing digital and cloud-based console gaming" which would allow delivery of older PlayStation titles to their newer devices (n.p.). By February 2014, Sony had launched PlayStation Now, a streaming game service that allows access to these older games (Molina 2014).

In early 2014, stock in Nintendo—creator of the portable gaming device—was downgraded in response to sales figures falling for three consecutive years, impacted by increased sales of digital games which are crushing the traditional console market (SuperData 2014b). In response, Nintendo is considering the transition to mobile platforms. This would be a major development for a company that has profiled its company's image around education. However, traditional gaming devices are not an outdated technology. In 2013, the average gamer still owned more than two consoles. Of these gamers, "over half own a Wii or Wii U, close to half own an Xbox 360 and just under half own a Playstation 3" (SuperData 2013b). Although the devices compete with each other, they are also complementary as they provide different experiences to gamers and the statistics show that dedicated gamers own them as part of a collection. Over the last 2 years, the three big players all launched new consoles: Microsoft's Xbox One (released in November 2013); Sony's PlayStation 4 (also released November 2013); and Nintendo's Wii U (launched a year earlier in November 2012).

With the pace of change and entry of new competitors into the market, industry observers are making comparisons with the early 1980s when companies such as Atari, Magnavox and Intellivision brought arcade games into people's homes via new gaming hardware.

> … people love flexibility. But gamers are also accustomed to particular environments in which they play each type of game. Consoles in the living room, casual mobile on the phone, and high-performance titles on PC. The danger is that developers will clamor to build for all these new devices, creating an atmosphere like that of the early 80s aimed more at pushing out a title to every device than making solid games. (SuperData 2013a, n.p.)

To this point, most companies (such as Nintendo, Sony and Microsoft) in the game developer market have a reputation for releasing games of a high quality, while the rush of game developers into the app market means less attention to quality control (Kain 2014, n.p.).

Although the PC industry has kept abreast of the digital games market, the flexibility of mobile devices appears to hold more appeal to buyers of new hardware. Even the well-established PC market is now threatened since the advent of digital tablets. Sussex (2012) describes tablets as a "game-changer", particularly in education, where tablets now threaten the sale of PCs in the USA education market.

Sussex describes tablets as being well suited to "interactive and shared learning… tablets help take us away from the teacher-fronted classroom and into more student-driven learning" (n.p.). However, tablets have their disadvantages, for example, typing text into a tablet is tedious and slow.

> All this means that tablets cannot yet be a total learning device. For what they do well they are fine. For the rest they need to be complemented. And using them effectively will require some rethinking of how we plan, execute, support and monitor learning. (n.p.)

The trend toward mobile devices will inevitably shape the architecture of games. At present, PCs have great processing power and as a result allow for graphics to be displayed in High Definition (and beyond) quality. This power also allows for detailed storylines in games, including serious games with the opportunity for complex decision making to occur. At present, mobile devices do not provide opportunity for open-ended gameplay or multiplayer simulations to the degree afforded by machines with high-end processing. Consequently, game designers are set the challenge to work productively in distinct markets. The following section describes digital games within this context.

Trends in Digital Games

New digital games are constantly emerging—both from global game manufacturers and from independent designers and developers. While the gaming device industry is largely controlled by global businesses (such as Microsoft, Apple, Nintendo and Google), games themselves are a more open playing field where independent designers can compete with big business—and gamers are the judge. For example, of the 20 billion apps downloaded from the Apple App Store in 2013, Apple's top three games for iPhone were all produced by independent developers (Ridiculous Fishing, Device 6 and Epoch 2), as was the top game for iPad (Badland) (Starr 2013).

The market is no longer controlled so tightly by the traditional game industry. That is, an open market has emerged for access to games outside of the previously dominant production companies. Gamers and independent game designers are becoming ever-stronger drivers of trends. For a deeper analysis of the current trends in games, below we consider the categories of online, subscription, mobile and console/handheld games.

Online and Subscription Games

A Digital Content Report for 2013 (IHS Technology and App Annie 2014, p. 13) that examined digital content trends around the world, highlights that the "PC is the strongest platform for digital games spend" and indicates that China is the largest market in terms of digital games for PC. The dominance of the platform is under threat, however, particularly from the mobile market. During 2013, in the USA and UK (the leading European market): "game apps saw the strongest growth, taking share from online games, which saw a slight decline" (p. 19).

Table 1 Types of online games played most often in the United States of America in 2009 and 2012 (Source: ESA 2010, 2013)

Type of online game	2009 (%)	2012 (%)
Puzzle, board game, game show, trivia, card games	42	34
Action, sports, strategy, role-playing	20	26
Persistent, multiplayer universe	14	14
Downloadable games	11	–
Casual, social games	–	19
Other	12	8

Nevertheless, online gaming is still incredibly popular. The ESA (2010, 2013) publishes data on the online game categories played most often in American gaming households. Table 1 shows how the type of game people played varied between 2009 and 2012. Over time, gamers played *less* puzzle, board, game show, trivia and card games; *more* action, sports, strategy and role-playing games; and the *same* persistent, multiplayer universe games. Downloadable games were played in 2009 but not in 2012, while casual social games that did not exist in 2009 were played by 19 % of gamers in 2012 (ESA 2010, 2013).

During 2013, the top ten online games in Western markets based on revenue (SuperData 2014a) were:

1. CrossFire;
2. League of Legends;
3. Dungeon Fighter Online;
4. World of Tanks;
5. Maplestory;
6. Lineage I;
7. World of Warcraft;
8. Star Wars: The Old Republic;
9. Team Fortress 2; and
10. Counter-Strike Online.

An analysis of the top-selling computer games in the USA between 2009 and 2012 shows the pace of change in the top 20 selling computer games: only four games (and their variants) appeared on both lists (The Sims, World of Warcraft, Starcraft, and Diablo); while 15 games appeared on only one of the top-selling lists in either 2009 or 2012 (ESA 2010, 2013).

Subscription games are a category within online games where players subscribe to join and play a digital game through their web browser; the game is housed online. Even though subscription games are trending downward (SuperData 2013d), they include some of the most popular digital games of all time. Subscription games include massively multiplayer online games (MMOG) where gamers from around the world join in a game. Due to the number of players and the online virtual environment, the *world* continues to exist and evolve while the player is offline. A popular variation of this genre is massively multiplayer online role-playing games (MMORPGs). As the name implies, role-playing digital games are incorporated into multiplayer online virtual worlds. The games have a culture all their own, with interaction between players, quests or challenges, and regular progression to encourage players at the limit of their skill level. The most subscribed of the MMORPGs is World of Warcraft, which was released in 2004 and by 2011 had a total playing time of 5.93 million years (McGonigal 2011). It is also the second largest wiki in the world—behind Wikipedia—and it contains the most information on a single topic than any other wiki in the world (McGonigal 2010).

The world's fastest growing MMORPG is Star Wars: The Old Republic, which was released in December 2011 and amassed 1 million subscribers in its first 3 days—it also appears on the 2013 top ten online game list above. An Electronic Arts (2011) press release stated that by the 3rd day after release, players had "logged 28 million in-game hours—roughly equivalent to watching all six *Star Wars* movies, two million times", with players averaging 5 h a day in the game (n.p.).

These cases of online engagement reveal not only the level of cross-cultural appeal but also the desire for gamers to belong to a community. This collaborative and community engagement occurs predominantly via the Internet in a virtual space. By contrast, mobile gaming provides the opportunity for face-to-face engagement.

Mobile Games

Apps are a main driver of the huge growth in digital games and also their increasing infiltration into countries which traditionally have not had a large digital games culture. This book contains three chapters exploring apps and their implication for education (see Bossomaier; Calder; Larkin this volume).

Apps are the mode of delivery for games on smartphones or tablets, which are the big players in the fast-growing mobile device market (although there are also others, such as Apple's iPod—designed to play music but with versions such as the iPod Touch that allows game apps to be downloaded). Smartphone users alone will total 175 billion worldwide in 2014 (eMarketer 2014), delivering a huge market for app developers and game designers keen to tap into the growing market for mobile and multipurpose devices.

Of the top ten app publishers in 2013, eight of them were "mobile centric", and while many made apps available for non-mobile platforms, mobile was their main focus for both "current strategy and revenue mix" (IHS Technology and App Annie 2014, p. 14). Market analysis shows that in 2013, for the first time, consumers spent more on app game downloads (for their mobile devices) than on dedicated handheld portable gaming systems—and toward the end of the year, the combined sales from the two main companies selling apps (the Apple App Store and Google Play) were triple the market for the traditional dedicated gaming market (App Annie 2014).

In 2013, Japan and South Korea were high adaptors of mobile applications. In fact, Japan "is the only country where spend is higher on mobile game apps than on other types of digital games (including mobile web)" and also where "apps have disrupted the traditionally strong mobile browser-based games business as consumers have quickly shifted to smartphone apps" (IHS Technology and App Annie 2014).

BRIC countries (Brazil, Russia, India and China) also performed strongly in the mobile game market, and analytics company App Annie (2014) anticipates growth in 2014 from new markets such as Hong Kong, Taiwan, Thailand, Mexico and Indonesia.

Apple and Google, the two major competitors in app development, tend to offer similar resources. Apple opened its App Store in July 2008 with 500 apps, which had grown to 850,000 apps by mid-2013 (for iPhone, iPad and iPod Touch users). In May 2013, Apple confirmed 50 billion app downloads, doubling the 25 million benchmark it achieved 14 months earlier in March 2012 (Lowensohn 2013). Apple's major rival for app downloads and sales is Google Play (launched in March 2012 with the merging of the Android Market and Google Music), the digital distribution platform for the Android operating system. Google Play announced that they had reached 48 billion downloads by May 2013—the same month Apple announced their 50 billion (Skillings 2013). By mid-2013, Google Play surpassed the App Store in downloads, finishing 15 % higher by the end of the year—but the App Store still generated twice the annual revenue of Google Play due to its stronger monetisation (App Annie 2014).

The top apps worldwide in 2013, based on downloads from both Apple and Google (App Annie 2014), were:

1. Candy Crush Saga;
2. Subway Surfers;
3. Temple Run 2;
4. Despicable Me;
5. Fruit Ninja;
6. Angry Birds;
7. Hill Climb Racing;
8. Pou;
9. 4 Pics 1 Word; and
10. Real Racing 3.

Game apps top the popularity lists amongst apps across both companies. During 2013, the most popular overall apps downloaded from the App Store were games—the most downloaded paid app was Minecraft and the most downloaded free app was Candy Crush Saga (Starr 2013). In Google Play, the top category of app downloads for the last 2 years has been games (App Annie 2014).

Console/Handheld Games

As mentioned earlier in the chapter, consoles and handheld gaming devices are trending down in the world of gaming. They are also less likely to feature in the education market, as schools encourage students to work on PCs or tablets in the classroom rather than single-purpose handheld gaming devices. In the playground, students are also as likely to have a smartphone with game apps installed than a traditional handheld gaming device.

However, the console segment of the market cannot be dismissed, particularly as most gamers use more than one device to game and dedicated gamers own a number of devices as part of a gaming collection (SuperData 2013b). Recently, the three big players all launched new consoles: Microsoft's Xbox One (released in November 2013); Sony's PlayStation 4 (also released November 2013); and Nintendo's Wii U (launched in November 2012). In 2014, new games will continue to be launched for the three new consoles: "The beauty of a shift in console generations is that it often sets off a wave of brand-new franchises" (Molina 2014). Many iconic games are associated with consoles, such as the Super Mario or Pokémon games produced by Nintendo, which are amongst the highest-selling video games of all time. These long-running series have a ready market, with loyalty and familiarity playing a part in game preference and selection.

Time magazine's iconic top ten of everything lists for the last 5 years (see Table 2) shows how quickly the games market is changing, even in the console market. From the 50 games featured in their top ten video game lists, only five games (Assassin's Creed, Batman, variants of Super Mario, Halo and Uncharted) appear in more than 1 year.

The console market has to remain abreast of new technologies. Instead of inserting a game cartridge into a console or handheld gaming device, technology

Table 2 Top ten video games from 2009 to 2013 (Source: *Time* magazine. (2009–2014). Top ten of everything lists. *Time Tech*. Retrieved from http://techland.time.com/)

2009	2010	2011	2012	2013
Modern Warfare 2	Alan Wake	Minecraft	Guild Wars 2	Grand Theft Auto V
Batman: Arkham Asylum	Angry Birds	Portal 2	Xenoblade Chronicles	Assassin's Creed IV: Black Flag
DJ Hero	Red Dead Redemption	The Legend of Zelda: Skyward Sword	XCOM: Enemy Unknown	Pokémon X & Y
Borderlands	Halo: Reach	Uncharted 3	Dishonored	Gone Home
New Super Mario Bros. Wii	Super Mario Galaxy 2	Batman: Arkham City	Assassin's Creed III	Animal Crossing: New Leaf
Geo-Defense Swarm	Limbo	Bastion	Papo & Yo	The Last of Us
Scribblenauts	Super Meat Boy	Skyrim	The Last Story	Pikmin 3
Halo 3: ODST	Super Street Fighter IV	Dark Souls	LittleBigPlanet	BioShock Infinite
Assassin's Creed 2	Starcraft II	Sword & Sworcery	Halo 4	Far Cry 3: Blood Dragon
Uncharted 2	Mass Effect 2	Battlefield 3	Torchlight III	Skylanders: Swap Force

company IHS "forecasts that 41 % of games spend on these devices will be digital by 2017 including service subscriptions" (they give Microsoft's Xbox Live Gold and Sony's PS Plus as examples) (IHS Technology and App Annie 2014, p. 13).

Although new games appear on these lists, many of the popular games belong to a series or genre that has been well established and previously successful. The mix of new storylines and familiar extensions of genre favourites highlight the need for the industry to create new opportunities while building on previous success.

Trends in Gaming Behaviour

The rise and fall of devices and digital games has impacted on the playing habits of both gamers and students in classrooms. Digital games have largely morphed from a solitary hobby into an interactive, collaborative experience. In the USA, 40 % of parents play computer and video games weekly with their children (and 58 % at least monthly), and the majority of all gamers (62 %) play with others, up from 59 % in 2008 (ESA 2010, 2013). Gaming conventions are also regularly held around the world, which bring together gamers to play, view new technology and discuss games.

As well as gaming with others in a physical sense, joining others in an online virtual world is also growing in popularity. The success of MMOGs and virtual worlds such as World of Warcraft and Star Wars: The Old Republic, provides evidence for the popularity of the interactive gaming experience. These games bring together gamers from around the world to game and collaborate, sometimes with millions of other people.

> A solitary pastime played on a box in the corner of a basement recreation room or bar barely resembles the collaborative educational, artistic and serious games simultaneously played on several continents by millions of contestants today. … In barely more than a generation, video games transformed from a diversion for the few into a mass medium, helping people live, learn, work and of course, play. (ESA 2012, p. 1)

Gamers are also no longer restricted by their devices to playing games at home or in a building with fixed hardware. Smartphones and tablets, and their ability to access wifi in most public spaces mean games can now be played anywhere wifi is available. In their 2013 report on the computer and video game industry, the USA-based ESA (2013) found that 36 % of gamers play on their smartphones and 25 % play on their wireless device. As a result, gaming now occurs in more locations and environments than ever before.

The magnitude of the popularity of digital gaming, and the increased flexibility in where and how to game, means that digital games can be—and are—used in new and innovative ways, including in the field of education. The next section looks at the societal and political influences of digital gaming followed by the reactions from education and research communities.

The Societal and Political Influences of Digital Gaming

To fully engage and inspire children on subjects like mathematics and science, educators and parents are beginning to take advantage of children's natural affinity for digital games. Games have attracted philanthropic foundations' and policy-makers' interest and may emerge as a new place to find common ground.

> In the past few years, a great deal of attention has been paid to the potential of digital games for good—President Barack Obama recently appointed an expert adviser to fashion the first national policy initiative on digital games' role in education, health, civic engagement, and numerous other areas. (Levine and Vaala 2013, p. 72)

Within the USA alone, The Department of Defense, National Science Foundation and National Institutes of Health have all expanded research and development funding in order to better understand the range of effects that well-deployed games can offer. In 2010, the Obama Administration, in cooperation with a wide range of philanthropic nonprofit children's organisations and industry partners, launched The National STEM (Science, Technology, Engineering and Math) Video Game Challenge—a national effort to encourage youth to create their own game-based solutions to teach essential knowledge and skills. "In 2011, Congress also launched a bipartisan E-Tech Caucus and supported a new Digital Promise initiative to promote public–private partnerships that advance innovation (including game-based solutions) in education" (Levine and Vaala 2013, p. 73). Such initiatives seek to address what the Bill and Melinda Gates Foundation considers a national crisis with student engagement (Civic Enterprises 2006). Indeed, the Gates Foundation is a large influence, having provided funding for 25 grants for games-related projects since 2009, totalling over US$24 million.

Within Australia, the Australian Government committed AU$16.2 billion in funding over 4 years to provide new facilities and refurbishments in Australian schools to meet the needs of twenty-first century students and teachers through the Building the Education Revolution (BER) program. The program provided not only improved infrastructure, but also digitally equipped classrooms. A search of the Australian Research Council website for research funding outcomes indicates that since 2009, seven separate projects involving digital games have been funded, alongside a 4-year, AU$16 million Special Research Initiative for a Science of Learning Research Centre. The Centre's main objective is the delivery of a program of activities that develop a strong evidence base for learning processes to inform teaching practices (Australian Research Council 2013). A key component of the Centre is understanding new ways of learning. Indeed, in the first bulletin published by the Centre, they briefly discuss the research they are undertaking with educational software (Science of Learning Research Centre 2013).

Screen Australia is the Australian Federal Government's agency for supporting the screen production sector. In November 2012 they took on the administration of a AU$20 million Interactive Games Fund "to help build a sustainable base for the Australian interactive entertainment industry" (Screen Australia n.d.). This funding is a response to concerns that the potential within Australia's games industry is not being reached and that there is a lack of trained graduates and highly skilled local staff to propel the industry forward.

The European Union has also funded several projects whose focus was on ICT and digital games. The Seventh Framework Programme for research and technological development (FP7) was the European Union's principal funding research over the period 2007 to 2013. This included a specific focus on technology-enhanced learning with such projects including the 80 days project <http://www.eightydays.eu/>, which was concerned with theories, methodologies, and technologies for game-based learning.

From our data search, there is evidence to suggest that the strength of growth in the games industry has influenced different political and philanthropic groups to consider how games can be used to help engage and educate society. The following section considers the response by the education and research communities to the use of games for learning and education.

Reactions from Education and Research Communities

The use of computer games in classrooms is not new to education; however the influence they are having over the education and educational research sectors has grown in the last 5 years (Krajewski 2014). In her popular 2010 TED talk, Jane McGonigal talks about the expertise gamers build during the many hours they spend in gameplay. She advocates that gaming can encourage the types of skills taught and valued in education, such as resilience, persistence, optimism and problem solving.

> When we play, we also have a sense of urgent optimism. We believe whole-heartedly that we are up to any challenge, and we become remarkably resilient in the face of failure. Research shows that gamers spend on average 80% of their time failing in game worlds, but instead of giving up, they stick with the difficult challenge and use the feedback of the game to get better. With some effort, we can learn to apply this resilience to the real-world challenges we face. (McGonigal 2011, n.p.)

A research team at the University of Wisconsin-Madison led by Constance Steinkuehler (Co-Director of video game research centre Games+Learning+Society) and Richard Davidson (Director of the Center for Investigating Healthy Minds) are undertaking studies that hope to demonstrate how video games "can strengthen the circuits in children's brains that regulate empathy, self-control, and the other 'non-cognitive' skills that researchers increasingly view as the foundation of lifelong academic, financial, physical, and emotional well-being" (Herold 2013, n.p.). The researchers intend to capitalise on the trend of digital media in education to show how it can support students in developing these valuable skills—and even make tasks such as assessment simpler and more reliable. With games able to log huge amounts of data, the team aims "to demonstrate that successfully playing a video game can itself constitute clear evidence of learning, eliminating the need for after-the-fact assessments" (Herold 2013, n.p.). Similarly, through careful observation, Fregola (this volume) identifies cognitive, psychomotor and socio-relational skills associated with gameplay and connects playing games to various learning theories developed well before digital games were commonplace.

Science is one field that has recognised the contribution gamers can make to solving real-world problems. Scientists have asked gamers to work out some long-standing scientific problems—by replicating them in a gaming world—often with rapid results. The online puzzle game, Foldit, is an example where the game situation provided opportunities for problem solving at very high cognitive levels:

> In 2011, people playing Foldit, an online puzzle game about protein folding, resolved the structure of an enzyme that causes an Aids-like disease in monkeys. Researchers had been working on the problem for 13 years. The gamers solved it in three weeks. (Mohammadi 2014, n.p.)

To play Foldit, gamers also needed to use mathematics, in particular 3D spatial skills, to manipulate chains of amino acids. Indeed, Lowrie (this volume) argues that visuospatial skills are becoming increasingly necessary in order to navigate a digital and more visually demanding world, suggesting gameplay provides opportunities for promoting such skills. This application of "school-based knowledge" within the gaming environment is one of the main reasons the education and research communities have taken notice of digital gaming. Van Eck (this volume) highlights that digital games are a good model for training and learning within situated, authentic problem-based environments. While transfer may not be evident, the process fosters learning and as a result is attractive to educators and researchers. Furthermore, Gros (this volume) acknowledges that social elements associated with motivation, engagement, adaptivity and collaboration enhance the prospects of games becoming an educational tool.

Indeed, there is much optimism linked to such research and the empirical evidence provided by these types of studies will be crucial to how the education and research communities move forward with digital games. The following section provides a snapshot of the impact of digital games on education and educational research.

Digital Game Themes in Education and Research

Throughout our search, three main themes emerged from the blogs, wikis, books and websites we accessed, namely: *gamification of education*, *game-based learning* and *edu-versioning of games*. We explore each of these themes in further detail below, explaining each one and considering its implications for education and research.

Gamification

Gamification is a term that has only been popular since 2010 and typically relates to applying game design thinking (such as the mechanics and dynamics of games) to non-game applications to make them more fun and engaging. This is a way of thinking and is essentially a process.

According to Gamification.org (n.d.), gamification has been labelled one of the most important trends in technology by several industry experts, claiming it can potentially be applied to any industry and almost anything to create fun and engaging experiences, converting users into players. Perrotta et al. (2013, p. ii) suggested gamification was "about using 'elements' derived from video game design, which are then deployed in a variety of contexts" including education. Gamification of education is taking these game elements, such as incentives, immediate feedback, rewards and more to classroom instruction. Much of the information about gamifying education relates to motivation, productivity, retention, mastery and changing learner behaviour. It suggests a shift in pedagogy. In their chapter on using a Kinect Sesame Street TV intervention to support counting activities in young children, Rothschild and Williams (this volume) examine the potential of using a digital game to transform or gamify a one-way information flow (watching television) into a potentially more engaging and interactive learning experience.

However, there have been some problems identified with gamifying a classroom, such as if the program is not well designed, it can become boring and predictable and activities can become meaningless. There are also ethical considerations about whether this type of pedagogy is actually manipulation or blackmail to get students to engage and achieve. Despite these conflicting views, the belief that the elements that make games fun and engaging will change teaching and learning is gaining momentum.

Digital Game-Based Learning

Digital game-based learning first became popular after Marc Prensky published his book of the same name in 2001 (re-published in 2007) and hence has been a topic of discussion for a number of years. Since this book's publication, some research has taken place into this notion of using games as a pedagogical approach to learning, however, it has really taken off in the last few years as gaming devices became more affordable. "Driven by their highly visual and engaging nature, games are now found everywhere, from medical and military simulations, to physical education courses, to publishing and advertising, and to corporate training" (Levine and Vaala 2013, p. 72). Game-based learning has been identified as "the use of video games to support teaching and learning" (Perrotta et al. 2013, p. i) focused around key principles such as motivation, authenticity and contextualisation, complex decision making, social experiences and self-reliance. It is a branch of serious games that deals with applications that have defined learning outcomes. Game-based learning balances subject matter learning and gameplay with the objectives of retaining and applying that subject matter in the real-world.

One of the problems identified with game-based learning is that the instructor/teacher needs to be very familiar with the games in order to address any issues students have. They must also have a clear understanding about how these games relate to curriculum outcomes and make those links clear to students. Often, it takes empirical research to find the right game to help teach the subject matter, not simply a quick Google search. As Beavis points out (this volume), game-based learning can be ‘messy’ to incorporate into the classroom; however, when based on good pedagogy and sound learning principles, games have the capacity to enhance conceptual understandings of complex processes in a range of subjects.

The Edu-Versioning of Games

Traditionally, digital games were marketed as either commercial or educational (Groom 2013, n.p.). Marketers tended to identify commercial games as fun and playful; while education games were traditionally seen as drill and practice. However, this is changing. As game-based learning becomes prominent, commercial game developers have produced *edu-versions* of their entertainment titles. Major labels and developers have already taken to creating versions of their games solely for education, many of which are linked to curriculum outcomes and standards (Groom 2013, n.p.). Electronic Art’s (EA) SimCity and Mojang’s Minecraft both have specific versions—SimCityEDU and MinecraftEdu respectively—designed to engage learners and assist educators.

Groom points out that the dilemma for educators is to identify which games are worth using as resources in the classroom. There are a broad range of games marketed as educational, but some are simply free apps with no link to educational learning outcomes beyond drill and practice. Where a shift has been is in those games that have been developed with close consultation between academic institutions and developers, such as SimCityEDU (see Farber 2013 for an example of how it is used in the classroom).

Both MinecraftEdu and SimCityEDU claim to focus on STEM curriculum and can provide a level of autonomy for teachers where they have *teacher only* control to modify and set the game up specifically for their students’ needs. However, unlike the free apps, such games are rarely free to download or play. MinecraftEdu advertises that schools can purchase the game for 50 % less the than the full price, while SimCityEDU also requires users to pay through various vendors. Consequently, education institutions need to be convinced of the academic importance and relevance before assigning money from the ever tightening budget to these ventures, possibly encouraging educators to look at other sources to bring game-based learning into their classrooms.

Finally, game developers also need to be careful when edu-versioning popular commercial games to make sure they do not break the ‘magic circle’ described by Avraamidou, Monaghan and Walker (this volume), which absorbs players in the world of the game (rather than real-world rules) and makes the games so appealing. In their chapter, Avraamidou, Monaghan and Walker consider the mathematics in non-school gameplay (which is mostly ‘invisible’ and integrated into the game) and ask whether these games can be transferred to a school mathematics environment.

The Infiltration of Digital Games into Educational Institutions

Specialist Schools

Our search revealed three specialist schools created with the intent to teach students for the twenty-first century based on the gamification premise. The three specialist schools are gamifying education: not only are classes based around game design principles, the entire curriculum has at its core gaming and game design. The first of these is located in New York. The *Quest to Learn School* was developed through the Institute of Play with the dedicated focus on developing children to work and play in the twenty-first century. The school claims that its critical mission "is a translation of the underlying form of games into a powerful pedagogical model for its 6–12th graders" and that the school "uses the underlying design principles of games to create highly immersive, game-like learning experiences" <http://q2l.org/curriculum>. A recent YouTube video by co-founder Katie Salen highlights some of the initiatives the school subscribes to <http://www.youtube.com/watch?v=Wk_OfUHpCbM>.

Also located in the USA and based on the same Quest model by the Institute of Play, the *Chicago Quest School*—a Chicago International Charter School—provides opportunities for students to learn in different ways through design and innovation, often with digital media. Both of these are public schools that have considered learning from different perspectives and claim to offer an innovative curriculum that is differentiated, challenge-based and focused on the key literacies of the twenty-first century, namely: design, collaboration and systems thinking and reasoning.

The third school is located in Brazil. *Oi Futuro Nave* (Advanced Educational Center) is a joint initiative by the largest of Brazil's telecommunication carriers, Oi, and the government of Rio De Janeiro. Again, a public school that has only been operating for several years, Oi Futuro Nave is thinking outside the square as it aims to prepare students for the inevitable digital life of the twenty-first century through providing opportunities to specialise in animation, game programming and script writing. The program is oriented toward using communication and information technologies in middle school, with the aim to continue the research and development of educational solutions.

Although these schools may well be seen as the way of the future, Bjerede (2013) has suggested the shift in thinking, from a pedagogical point of view, is akin to the shift from direct instruction to constructivism, and that educators need to be disrupted to see the potential. Research into the effectiveness of these schools needs to be undertaken in order to better assess their long-term viability.

University and College Courses

Universities and tertiary education providers are expected to be leaders in the area of education. They are, for all intent and purposes, educating the workforce of the future. Most universities now have blended learning options, combining online and face-to-face learning or even fully online MOOCs (Massive Open Online Courses). These options are seen to be leading the way with regard to access to qualifications for the majority, not the minority. Our search identified that tertiary education providers were abreast of the changing social climate and the needs of the consumer workforce, with an abundance of courses and subjects dedicated to gaming and game design. From community colleges through to the leading universities, the variation and distribution of the courses available were widely distributed and highlighted a mix of qualifications, departments and interests. Possibly the most obvious place to find game-related courses was in the computer science field. Indeed, many undergraduate and postgraduate courses fell under the Bachelor of Computer Science and Master of Science or similar. Some of the courses included *De Paul University College of Computing and Digital Media* (Chicago): Master of Science Computer Game Development; *Coventry University Serious Games Institute* (UK): Master of Science in Digital Games and Business Innovation; and *University of Skövde* (Sweden): Master of Science Serious Games.

There were also many courses that fell under the Arts such as *HKU University of the Arts* (Utrecht): Master of Arts Creative Design for Digital Cultures; *New York University Game Centre*: Master of Fine Art (explored the design and development of games as a creative practice); *Zurich University of the Arts*: Master of Arts in Game Design; and *Brunel University* (London): Master of Arts Digital Games Theory and Design. All courses provided a slightly different focus to the overarching gaming and game design theories.

The search revealed a variety of content offered within the courses. There were broad themes such as games studies, games technology and development, learning technologies, serious games and media and entertainment. A closer look at the courses highlighted an even broader connection to non-gaming content. Dalla Vecchia, Maltempi and Borba (this volume) investigated digital games as an environment for mathematical modelling within a course entitled *Construction of Electronic Games*. Other areas that such courses linked to were: artificial intelligence; information studies; engineering; learning and education; multimedia; human computer/media interactions; entertainment; and business. Given the cross-connections to such a variety of areas as evidenced by the university courses, it seems many qualifications in the future could have elements of gaming and game theory attached to them and it could be that the workforce may even demand it.

The Infiltration of Digital Games into the Research Community

Research and Professional Conferences

An important recurring feature of our analysis was the increase in professional and research conferences based around digital game-based learning and gamification. Many conferences are international, while others are more localised. Not surprisingly the majority of the conferences are relatively new; however, some of the established education conferences such as Computers in Education (in its 21st year) and Society for Information Technology and Teacher Education (SITE, in its 25th year) have themes or interest groups promoting the use and research of digital games and simulations in education. Indeed, the International Simulation and Gaming Association will present its 45th conference in 2014 with the theme *The Shift from Teaching to Learning: Individual, Collective and Organizational Learning through Gaming and Simulation*. Other conferences are concerned with serious games, artificial intelligence in games and the social aspect of games.

From a focused education point of view, some of the newer conferences related to game-based learning and gamification are the: European Conference on Games-Based Learning; The Games Learning Society Conference; Conference of the Digital Games Research Association; Games for Change Festival; and GSummit. All of these conferences aim to understand how video games, and digital and social media are having a positive impact on learning while developing essential skills that learners and the industry require to compete in the twenty-first century.

The influence of games for learning and digital aspects of learning has reached even smaller jurisdictions such as the state of Victoria in Australia, with the ICT in Education Victoria: Professional Teachers' Association presenting a workshop on *Practical Digital Learning and Teaching* for interested teachers. It featured workshops focusing on tools and tactics to effectively implement learning technology into regular classroom practice.

Such conferences and professional development highlights the impact and exposure the games sector is generating in the education sector. Educators are using these opportunities to share and strengthen their knowledge in integrating emerging technologies into learning environments. The conferences also highlight the interest from academia and professional associations in developing a sound research and evidence base for using digital games in learning.

Research Centres and Game-Based Associations, Networks and Businesses

Globally, many centres, associations and businesses have evolved that are dedicated to understanding the influence and impact of games and gaming on learning. Three of the most prominent in the authors' search were the Joan Ganz Cooney Centre <http://www.joanganzcooneycenter.org/about-us/>, the Games+Learning+Society <http://www.gameslearningsociety.org/index.php> and Games2Train <http://www.games2train.com/>, Marc Prensky's own company.

The Joan Ganz Cooney Centre is an innovative independent research laboratory that focuses on generating new ways of teaching children within the rapidly changing technological scene. The prominent underlying question of the Centre is *how can emerging media help children learn?* Funded by various philanthropic, government and business enterprises, the Centre considers all aspects of children's learning through different media. They recently conducted a national (USA) survey on teachers' attitudes about digital games in the classroom, along with video case studies of teachers attempting to utilise digital games in their classroom practice. Initial results suggested that of the 505 teachers who undertook the survey, 32 %

use games 2–4 days per week and that primary (elementary) school teachers are using them more frequently than middle school teachers. Most teachers agreed that games in the classroom increased motivation and engagement and increased collaboration among students. Many other centres operate under similar circumstances and for similar purposes. Some of these include: The Institute of Play (USA); The Games for Learning Institute (G4LI) (USA); Centre for Transformational Games (Edith Cowan University, Australia); The Arts Education Research Centre: digital.arts.research.education (DARE) (Institute of Education, University of London and the British Film Institute); The Serious Games Institute (Coventry University, UK); and The Learnovate Centre (Ireland). There is growing momentum in the dedicated research that is taking place to better understand how games and gaming theory are influencing society and education.

In parallel with the influx of conferences and centres is the amalgamation of people with interests in gaming and games in education. The Games+Learning+Society is a good example. Under the leadership of Co-Director Constance Steinkuehler, and with a centre operating out of the University of Wisconsin-Madison, this Society offers a place for like-minded people to interact, attend their self-run conference, undertake university courses on video games and learning, and develop their own games that all have an educational focus. This society is also part of a larger organisation called the Learning Games Network. This Network promotes "games, tools and communities for a new generation of playful learning" <http://www.learninggamesnetwork.org/>. An example of this in action is Playful Learning, an online portal designed for teachers to use in their classroom to explore, discover and use games for learning. Other associations include:

- The City University of New York (CUNY) Games network
  <http://games.commons.gc.cuny.edu/category/math-games/>
- Hong Kong Digital Game-Based Learning Association
  <http://www.digitalgameslearning.org/>
- Irish Learning Technology Association
  <http://ilta.ie/>

The increased societal presence has persuaded many businesses to follow the potential of the gaming industry and design games and other resources that teachers can pay for, and then use in the classroom. Although established a number of years ago, Marc Prensky's business Games2Train offers users the opportunity to become *certified* by playing the games. Other companies target schools and teachers specifically, such as DimensionU <http://www.dimensionu.com/dimu/home/home.aspx> and Learning.com with Aha! Math <http://www.learning.com/ahamath/> and Aha! Science <http://www.learning.com/ahascience/>. Both of these businesses, for example, offer access to games and other online resources to use in the classroom for a fee. DimensionU claims to create "engaging and interactive multiplayer video games that focus on core skills in mathematics and literacy". The selling point for these businesses is that they claim to align with curriculum standards and classroom instruction.

While these types of businesses will flourish in the current climate, any long-term change in pedagogy and classroom practice will require more than what these businesses can offer. A better understanding of the market and the educational value of using games to aid teaching and learning might see an increase in such businesses being successful.

Interpretation and Evaluation

The data we found and utilised in this chapter was by no means exhaustive; rather it was a snapshot of the information available on this topic in an attempt to understand where the field was situated. The current trends and themes in this chapter are a reference point and can be used when comparing future innovations. It is impossible to forecast "the next big thing" in digital games but change is certain. The challenge for educators is to make effective use of a technology that students are increasingly engaged with; to thoughtfully integrate it into learning environments; to consider how it can improve aspects of education such as assessment; and to use the technology in an affordable and accessible way.

It is likely that the generation of children now experiencing a parallel education in digital games, perhaps attending a specialist school, or going on to study game design at university, will strengthen the digital game culture. Perhaps future generations of digitally savvy students will grow and compound the use of digital games in learning as they themselves become our future educators and policy-makers.

Instead of separating out-of-school and in-school learning, digital games promise another way: "…they have potential to bridge the learning that children can do across life domains and settings" (Thai, Lowenstein, Ching, and Rejeski 2009, cited in Levine and Vaala 2013, p. 73). Learning is not restricted to one particular setting, i.e., school *or* home, but occurs everywhere. Learning environments can extend and complement each other rather than competing—and digital games are one way of doing this. Particularly if, to quote Jane McGonigal (2010, 2011), we can "harness this gamer power to solve real-world problems". Therein lies enormous potential.

References

App Annie. (2014). *App Annie index: 2013 retrospective: The top trends of 2013*. San Francisco: Author. http://blog.appannie.com/app-annie-index-retrospective-2013/. Accessed 8 Jan 2014.

Australian Research Council. (2013). ARC special research initiative for a science of learning research centre. http://www.arc.gov.au/ncgp/sri/slrc_selrpt.htm#approved. Accessed 20 Jan 2014.

Best, J. W., & Khan, J. V. (2006). *Research in education* (10th ed.). New York: Pearson.

Bjerede, M. (2013, 4 Nov). Disrupting pedagogy: Part 2. http://gettingsmart.com/2013/11/disrupting-pedagogy-part-2/. Accessed 20 Jan 2014.

Civic Enterprises in association with Peter D. Hart Research Associates. (2006). *The silent epidemic: Perspectives of high school dropouts*. Seattle: The Bill & Melinda Gates Foundation. http://files.eric.ed.gov/fulltext/ED513444.pdf. Accessed 27 Feb 2015.

Electronic Arts [EA]. (2011, 23 Dec). Star Wars: The Old Republic jumps to light speed [Press release]. http://investor.ea.com/releasedetail.cfm?ReleaseID=635238. Accessed 28 Jan 2014.

eMarketer. (2014, 16 Jan). Smartphone users worldwide will total 1.75 billion in 2014. *eMarketer Newsletter*. http://www.emarketer.com/Article/Smartphone-Users-Worldwide-Will-Total-175-Billion-2014/1010536. Accessed 28 Jan 2014.

Entertainment Software Association [ESA]. (2010). *2010 sales, demographic and usage data: Essential facts about the computer and video game industry*. Washington, DC: Author. http://www.theesa.com/facts/pdfs/esa_essential_facts_2010.pdf. Accessed 28 Jan 2014.

Entertainment Software Association [ESA]. (2012). The transformation of the video game industry. http://www.theesa.com/games-improving-what-matters/The_Transformation_of_the_Video_Game_Industry.pdf. Accessed 28 Jan 2014.

Entertainment Software Association [ESA]. (2013). *2013 sales, demographic and usage data: Essential facts about the computer and video game industry*. Washington, DC: Author. http://www.theesa.com/facts/pdfs/ESA_EF_2013.pdf. Accessed 28 Jan 2014.

Farber, M. (2013). Game-based learning in practice. *Edutopia*. http://www.edutopia.org/blog/game-based-learning-in-practice-matthew-farber. Accessed 8 Jan 2014.

Fayyad, U., Piatetsky-Shapiro, G., & Smyth, P. (1996). From data mining to knowledge discovery in databases. *AI Magazine, 17*(3), 37–54.

Gamification.org. (n. d.). http://badgeville.com/wiki/. Accessed 20 Jan 2014.

Groom, D. (2013, 10 Dec). Edu-games hit the market, but not all are created equal. The Conversation. http://theconversation.com/edu-games-hit-the-market-but-not-all-are-are-created-equal-20148. Accessed 8 Jan 2014.

Hand, D. J. (1998). Data mining: Statistics and more? *The American Statistician, 52*(2), 112–118.

Herold, B. (2013, 7 Aug). Researchers see video games as testing, learning skills. *Education Week*. http://www.edweek.org/ew/articles/2013/08/07/37games_ep.h32.html. Accessed 30 Jan 2014.

Herring, S. C. (2010). Web content analysis: Expanding the paradigm. In J. Hunsinger, L. Klastrup, & M. Allen (Eds.), *International handbook of Internet research* (pp. 233–249). The Netherlands: Springer.

IHS Technology & App Annie. (2014). *Digital content report 2013: Global shift driven by dramatic growth of apps* (White Paper). US: Author.

Kain, E. (2014, 6 Feb). Why the video game industry needs Nintendo to succeed. *Forbes*. http://www.forbes.com/sites/erikkain/2014/02/06/why-the-video-game-industry-needs-nintendo-to-succeed/. Accessed 10 Feb 2014.

Krajewski, J. (2014). 'You have died of dysentery': How games will revolutionize education. *Gamasutra*. http://www.gamasutra.com/blogs/JohnKrajewski/20140114/208612/You_Have_Died_of_Dysentery_How_Games_Will_Revolutionize_Education.php. Accessed 30 Jan 2014.

Levine, M. H., & Vaala, S. E. (2013). Games for learning: Vast wasteland or a digital promise? In F. C. Blumberg & S. M. Fisch (Eds.), *Digital games: A context for cognitive development. New Directions for Child and Adolescent Development, 139* (pp. 71–82). San Francisco: Wiley.

Lowensohn, J. (2013, 16 May). Apple's App Store downloads hit 50 billion. *CNET Australia*. http://www.cnet.com.au/apples-app-store-downloads-hit-50-billion-339344292.htm. Accessed 8 Jan 2014.

McGonigal, J. (2010, March). Gaming can make a better world. TED: Ideas Worth Spreading. http://www.ted.com/talks/jane_mcgonigal_gaming_can_make_a_better_world.html. Accessed 8 Jan 2014.

McGonigal, J. (2011). Be a gamer, save the world. *The Wall Street Journal*. http://online.wsj.com/news/articles/SB10001424052748704590704576092460302990884. Accessed 8 Jan 2014.

McMillan, S. J. (2000). The microscope and the moving target: The challenge of applying content analysis to the World Wide Web. *Journalism and Mass Communication Quarterly, 77*(1), 80–98.

Mohammadi, D. (2014, 26 Jan). How online gamers are solving science's biggest problems. *The Observer*. http://www.theguardian.com/technology/2014/jan/25/online-gamers-solving-sciences-biggest-problems. Accessed 30 Jan 2014.

Molina, B. (2014, 6 Feb). Video games in 2014: Five key questions. *USA Today*. http://www.usatoday.com/story/tech/gaming/2014/02/06/five-questions-video-games/5221777/. Accessed 10 Feb 2014.

Moses, A. (2013, 14 Feb). Video games thumped by apps. *The Sydney Morning Herald*. http://www.smh.com.au/technology/technology-news/video-games-thumped-by-apps-20130213-2edda.html. Accessed 28 Jan 2014.

Payne, G., & Payne, J. (2004). *Key concepts in social research*. London: Sage.

Perrotta, C., Featherstone, G., Aston, H., & Houghton, E. (2013). Game-based learning: Latest evidence and future directions (NFER Research Programme: Innovation in Education). Slough: NFER.

Portnow, J. (2010, 20 Jan). Analysis: Inside Brazil's video game ecosystem [Web log post]. http://www.gamasutra.com/view/news/26645/Analysis_Inside_Brazils_Video_Game_Ecosystem.php. Accessed 28 Jan 2014.

Science of Learning Research Centre. (2013). SLRC Quarterly: Spring 2013. http://www.slrc.org.au/wp-content/uploads/2013/12/SLRC_Bulletin_Nov2013_WEB1.pdf. Accessed 20 Jan 2014.

Screen Australia. (n. d.). Interactive games fund consultation. http://screenaustralia.gov.au/funding/games/default.aspx. Accessed 14 Jan 2014.

Skillings, J. (2013, 17 May). Apple reveals details of 50 billionth App Store download. *CNET Australia*. http://www.cnet.com.au/apple-reveals-details-of-50-billionth-app-store-download-339344308.htm. Accessed 8 Jan 2014.

Starr, M. (2013, 18 Dec). Apple announces its best apps of 2013. *CNET Australia*. http://www.cnet.com.au/apple-announces-its-best-apps-of-2013-339346257.htm. Accessed 8 Jan 2014.

SuperData. (2013a, 11 Jan). Are we headed for the video game crash of 2013? http://www.superdataresearch.com/blog/are-we-headed-for-the-video-game-crash-of-2013/. Accessed 14 Jan 2014.

SuperData. (2013b, 10 April). How many consoles is too many consoles? http://www.superdataresearch.com/blog/how-many-consoles-is-too-many-consoles/. Accessed 14 Jan 2014.

SuperData. (2013c, 23 Oct). Can Brazil lead the $3.9B digital games market in Latin America? http://www.superdataresearch.com/blog/brazil-games-market/. Accessed 14 Jan 2014.

SuperData. (2013d, 18 Dec). Infographic: Digital games year in review 2013 [Web log post]. http://www.superdataresearch.com/blog/infographic-digital-games-year-review-2013/. Accessed 14 Jan 2014.

SuperData. (2014a, 16 Jan). US digital games market update: December 2013 [Web log post]. http://www.superdataresearch.com/blog/us-digital-games-market/. Accessed 14 Jan 2014.

SuperData. (2014b, 28 Jan). Nintendo's $2.7B mobile games opportunity that's never going to happen [Web log post]. http://www.superdataresearch.com/blog/nintendo-mobile-games/. Accessed 14 Jan 2014.

Sussex, R. (2012, 27 Sept). Finger-flicking good: Have digital tablets become essential? *The Conversation*. http://theconversation.com/finger-flicking-good-have-digital-tablets-become-essential-9649. Accessed 8 Jan 2014.

Time magazine. (2009–2014). Top ten of everything lists. *Time Tech*. http://techland.time.com/. Accessed 14 Jan 2014.

Tracy Logan is Assistant Professor in the Faculty of Education, Science, Technology and Mathematics at the University of Canberra. As an early career academic, most of Tracy's research has emerged from involvement in five Australian Research Council (ARC) Discovery grants. Her areas of strength reside within students' spatial reasoning, mathematics assessment and the use of digital tools for mathematics sense making. Tracy's research involves a range of mixed-paradigm research methodologies, including data collection in longitudinal mass-testing situations; one-on-one interviews; cross-country comparisons of students' numeracy development; student and teacher focus groups; longitudinal case studies; and stimulated recall. Tracy is currently undertaking a PhD at the University of Canberra in the area of mathematics education, with a focus on secondary data analysis utilising a sophisticated framework that analyses both quantitative and qualitative data.

Kim Woodland works in the Research Institute for Professional Practice, Learning and Education (RIPPLE) at Charles Sturt University in Australia. She has worked as a research assistant in mathematics education, focusing on spatial reasoning and visual imagery, including assisting with a number of Australian Research Council funded projects—including *Mathematics in the Digital Age: Reframing Learning Opportunities for Disadvantaged Indigenous and Rural Students.* She has also assisted in the editorial process for a range of books, book chapters, journal articles and conference papers in mathematics education for primary school students.

Index

Digital Games and Mathematics Learning

© Springer Science+Business Media Dordrecht 2015

T. Lowrie, R. Jorgensen (Zevenbergen) (eds.), *Digital Games and Mathematics Learning,*
Mathematics Education in the Digital Era 4, DOI 10.1007/978-94-017-9517-3

PEOPLE