Smart Computing and Intelligence
Series Editors: Kinshuk · Ronghuai Huang · Chris Dede

Paloma Díaz
Andri Ioannou
Kaushal Kumar Bhagat
J. Michael Spector *Editors*

Learning in a Digital World

Perspective on Interactive Technologies for Formal and Informal Education

Springer

Smart Computing and Intelligence

Series Editors

This book series aims to establish itself as a medium for the publication of new research and development of innovative paradigms, models, architectures, conceptual underpinnings and practical implementations encompassed within smart computing and intelligence.

The scope of the series includes but is not limited to smart city, smart education, health informatics, smart ecology, data and computational analytics, smart society, smart learning, complex systems-chaos, computational thinking, brain computer interaction, natural/computer interaction, humanoid behaviour, and impact of educational psychology on computing.

The cornerstone of this series' editorial policy is its unwavering commitment to report the latest results from all areas of smart computing and intelligence research, development, and practice. Our mission is to serve the global smart computing and intelligence community by providing a most valuable publication service.

More information about this series at http://www.springer.com/series/15620

Paloma Díaz · Andri Ioannou ·
Kaushal Kumar Bhagat ·
J. Michael Spector
Editors

Learning in a Digital World

Perspective on Interactive Technologies for Formal and Informal Education

Springer

Editors
Paloma Díaz
Carlos III University of Madrid
Leganés, Spain

Andri Ioannou
Cyprus University of Technology
Lemesos, Cyprus

Kaushal Kumar Bhagat
Centre for Educational Technology
Indian Institute of Technology
Kharagpur, India

J. Michael Spector
University of North Texas
Denton, TX, USA

ISSN 2522-0888 ISSN 2522-0896 (electronic)
Smart Computing and Intelligence
ISBN 978-981-13-8264-2 ISBN 978-981-13-8265-9 (eBook)
https://doi.org/10.1007/978-981-13-8265-9

© Springer Nature Singapore Pte Ltd. 2019
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, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Contents

Editors and Contributors

About the Editors

Prof. Dr. Paloma Díaz is a Full Professor at the Department of Computer Science and Engineering of Universidad Carlos III de Madrid. With a degree and Ph.D. in Computer Science and Engineering from Universidad Politécnica de Madrid, she has been involved in interdisciplinary research in the Interactive Systems research group (DEI LAB) and the Institute of Culture and Technology from UC3M. Her main areas of interest are interaction design, web/usability engineering, mobile and ubiquitous computing, big data visualization, civic participation, ICT for learning and teaching, and digital cultural heritage. Since 1996, she leads the DEI LAB (www.dei.inf.uc3m.es) that is focused on the design and development of interactive systems, data visualizations, collaborative systems, and learning and simulation. The group does use-inspired basic research in areas such as emergency and crisis management, operation control, elearning and training, and cultural heritage and it also goes into enabling research to devise the capabilities of emerging interactive devices. Dr. Díaz has led national and international research projects about the application of interactive technologies for design, learning and training, crisis management, civic participation or the operation of electrical smart grids. Some of her publications can be reached at dblp and researchGate. She has also organized international conferences and symposiums like IEEE ICALT 2008, IEEE VLHCC 2010, and IS-EUD 2015, ISCRAM-MEd 2017 as well as tracks in conferences such as Social Networking and Collaboration at ISCRAM 2010–2013, Serious games and simulation at ISCRAM 2014–2015, Creativity in Collaborative Design at ACM Cognition and Creativity 2015, or the track Technologies for Open Learning and Education at ICALT 2017 and ICALT 2018.

Dr. Andri Ioannou is an Assistant Professor in the Department of Multimedia and Graphic Arts of the Cyprus University of Technology, Director of the Cyprus Interaction Research Lab (https://www.cyprusinteractionlab.com/), and Team Leader of the "Educational Media for Education and Edutainment" Multidisciplinary research Group within the Research Centre for Interactive Media, Smart Systems, and Emerging Technologies (RISE) of Cyprus. Andri has a Ph.D. in Educational Technology from the University of Connecticut, USA, an MA in Education from the same University, and a BSc in Computer Science from the University of Cyprus. Her research interests contribute to several key areas of Educational Technology, including (i) design and evaluation of innovative educational technologies and learning environments; (ii) development and evaluation of pedagogical frameworks and ICT tools for learning in both distant and collocated, formal and non-formal learning settings; (iii) study of tools and pedagogies targeting the development of skills within the twenty-first-century learning framework, collaboration, problem solving, leaving-in-the-world skills; (iv) use of educational technology for social change. Dr. Ioannou has established a respected research record through numerous publications in prestigious international journals and international conferences (e.g., Computers in Human behaviour, Interactive with Computers, Education Technology and Society, Educational Technology Research and Development, Educational Computing research etc.). Dr. Andri Ioannou has obtained considerable funding in support of her research from funding agencies in Cyprus and the EU. She has participated in the capacity of coordinator or research collaborator in programmes of the H2020 framework, Erasmus+ and programs of the Cyprus National Research Foundation, focused on technology-enhanced learning in K-12, higher education and vocational training (e.g., KA2 Project INTELed 2017-1-CY01-KA201-026733, ENGINITE 2017-1-CY01-KA202-026728, H2020-WIDESPREAD-01-2016–2017grant no: 739578, NOTRE H2020-TWINN grant No: 692058).

Dr. Kaushal Kumar Bhagat is currently working as an Assistant Professor in the Centre for Educational Technology at the Indian Institute of Technology (IIT), Kharagpur, India. He received his Ph.D. from the Graduate Institute of Science Education at the National Taiwan Normal University in September 2016. He then served a 2-year postdoctoral position at the Smart Learning Institute at Beijing Normal University. He has published several referred journal articles and book chapters. Dr. Bhagat was presented NTNU International Outstanding Achievement Award. He was also awarded 2017 IEEE TCLT Young Researcher award. His research area of interest includes online learning, augmented reality, virtual reality, mathematics education, flipped classroom, formative assessment, and technology-enhanced learning.

Prof. J. Michael Spector is a Professor of Learning Technologies at the University of North Texas. He has been Editor of Educational Technology Research & Development for 15 years. He edited the third and fourth editions of the Handbook of Research on Educational Communications and Technology as well as the Encyclopedia of Educational Technology. His research focuses on intelligent support for instructional design, assessing learning in complex domains, and technology integration in education.

Contributors

Leonard A. Annetta as the Taft Distinguished Professor of Science Education at East Carolina University, Dr. Annetta's research has focused on innovative technologies and the effect of Serious Educational Games on science learning of teachers and students in underserved populations. He has been awarded over $19 million as Lead Principal Investigator for his research to date and has won numerous awards and honors for his work.

In 2008, Dr. Annetta was honored with three awards for his extension work teaching K-12 teachers and students' video game design and creation. These awards were progressive from the College of Education Outstanding Extension Service Award, to the induction into the NC State University Academy of Outstanding Faculty Engaged in Extension to the Distinguished Alumni Engaged in Extension and Outreach award. Moreover, Dr. Annetta has twice been awarded the National Technology Leadership Initiative Fellowship in Science Education and Technology from the Association of Science Teacher Education and the Society for Information Technology and Teacher Education. He has thrice been invited to the National Science and Engineering Festival as one of the top 50 speakers in STEM. www.Lenannetta.com

Jordan Beck is an Assistant Research Professor in the College of Information Sciences and Technology and is a member of the Center for Human–Computer Interaction. His research focuses on understanding knowledge production practices in academia and online peer production communities. He is, especially, interested in identifying how these practices might be supported or constrained by interaction design.

R. Benjamin Shapiro is an Assistant Professor of Computer Science at the University of Colorado Boulder. He conducts research on creative learning with programmable technologies and, more broadly, on making and learning with technology. He earned his doctorate in Learning Sciences at Northwestern University.

Dr. Scott W. Brown is a University of Connecticut *Board of Trustees' Distinguished Professor of Educational Psychology* and Department Head of Educational Psychology at UConn. Dr. Brown has authored more than 170 journal articles and book chapters, 3 books and presented his research on problem-based learning, simulations, memory, and educational technology at international, national, and regional professional conferences. Dr. Brown is a Fellow in both the American Educational Research Association and the Association for Psychological Science. He has received grants from the US Department of Education, NSF, the CDC and the Carnegie Corporation, totalling more than $15M (USA). Dr. Brown currently serves as the co-principal investigator on the GlobalEd 2 Efficacy Trials grant and 2017 GlobalEd 2.

Huiying Cai is an Associate Professor of Department of Educational Technology, Jiangnan University. She obtained her Ph.D. degree in East China Normal University, mentored by Prof. Xiaoqing Gu. Her main research interests are computer-supported collaborative learning and classroom research.

John M. Carroll is a Distinguished Professor of Information Sciences and Technology at the Pennsylvania State University. His research is in methods and theory in human–computer interaction, design of interactive information systems for collaborative learning and problem-solving, and spontaneous innovations of people interacting with technology-mediated problems and possibilities. Recent books include *Learning in Communities* (Springer, 2009), *The Neighborhood in the Internet: Design Research Projects in Community Informatics* (Routledge, 2012), *Creativity and Rationale: Enhancing Human Experience by Design* (Springer, 2012), and *Innovative Practices in Teaching Information Sciences and Technology* (Springer, 2014). Carroll serves on several advisory and editorial boards for journals, handbooks, and series. He is editor of the *Synthesis Lectures on Human-Centered Informatics*. Carroll has received the Rigo Award and the CHI Lifetime Achievement Award from ACM, the Silver Core Award from IFIP, the Goldsmith Award from IEEE, and an honorary doctorate in engineering from Universidad Carlos III de Madrid. He is a fellow of AAAS, ACM, IEEE, the Human Factors and Ergonomics Society, the Psychonomics Society, the Society for Technical Communication, and the Association for Psychological Science. In 2018, he received the Faculty Scholar Medal in Social and Behavioral Science from Penn State.

Dr. Maiga Chang is a Full Professor in the School of Computing Information and Systems at Athabasca University, Canada. He is now Chair of IEEE Technical Committee of Learning Technology (TCLT). He is Editor in Chief of International Journal of Distance Education Technologies (an EI and Web of Science's ESCI journal without publication fee) and Section Editor of Education and Science (a free SSCI Open Access journal). Dr. Chang also serves academic international conference events include being program chair of International Conference on Smart Learning Environments (ICSLE 2015, 2018, and 2019), general program chair of IEEE TCLT flagship conference International Conference on Advanced Learning Technologies (IEEE ICALT 2017 to 2019), Program Committee Chair of 15th International Conference on Intelligent Tutoring Systems (ITS 2019), IPC Coordination Co-Chair of International Conference on Computers in Education (ICCE 2018), executive program chair and program co-chair of Global Chinese Conference on Computers in Education (GCCCE) in 2017 and 2016. He has given more than 90 talks and lectures in different conferences, universities, and events. He has participated in more than 290 international conferences and workshops as a Program Committee Member; and, he also has (co-)authored more than 234 proceedings, edited books, special issues, book chapters, journal, and international conference papers.

Cheng-Li Chen received his B.S degree in Information Science and Management Systems from Nation Taitung University, Taiwan in 2009. Since 2011, he started to work on his master degree in Information Management at National Kaohsiung First University of Science and Technology, Taiwan and completed it in 2017. He is now a master's student of School of Computing and Information Systems at Athabasca University, Canada, and works on his second master degree. His master thesis supervisor is Dr. Maiga Chang. For his thesis research, he thinks that compared to traditional rewards such as stamps or stickers, the use of in-game items as rewards can attract students much more and can get them motivated to put more efforts on doing their homework and participating in learning activities in online learning environment; for instance, doing discussions with peers in the discussion forums.

Dr. Nian-Shing Chen is currently the Feng Tay Chair Professor in the Department of Applied Foreign Languages at National Yunlin University of Science and Technology, Taiwan. He has published over 400 papers in the international referred journals, conferences and book chapters. One of his papers published in Innovations in Education and Teaching International was awarded as the top cited article in 2011. He is an author of three books with one textbook entitled "e-Learning Theory & Practice". Dr. Chen received three outstanding research awards from the National Science Council, Taiwan in 2008, 2011–2013 and the Ministry of Science and Technology in 2015–2017. His current research interests include assessing e-Learning course performance; online synchronous teaching and learning; mobile and ubiquitous learning; game-based learning and cognition & Gesture-based learning. Prof. Chen is serving as an editorial board member for many international journals and guest editors for special issues of international journals. He has also organized and chaired numerous international conferences and workshops in the area of advanced learning technologies. Professor Chen is a senior and golden core member of IEEE, ACM and the current Chair for the IEEE Technical Committee on Learning Technology (http://lttf.ieee.org/). He was Editor in Chief of the SSCI indexed Journal of Educational Technology & Society.

Sie Wai Chew is a doctoral candidate in the Department of Information Management at National Sun Yat-sen University, Taiwan. She received her masters in Applied Statistics from University Malaya (UM), Malaysia in 2009. Her research interests include Critical Thinking Skill, English as a Second Language and System Design in Learning Technology. She served as the Editorial Assistant of the SSCI indexed Journal of Educational Technology & Society.

Maria Christofi is a Ph.D. candidate at the Department of Multimedia and Graphic Arts. She holds a BSc in Computer Science (2014) from the University of Cyprus and a MSc in Design and Development of Computer Games and Interactive Technologies (2015) from the Cyprus University of Technology and the University of Cyprus. She is currently a research associate at H2020-TEAMING-RISE (Stage2) project. Her research interests include virtual reality, video games, body ownership, and psychology.

Yiannis Georgiou is a postdoctoral researcher with the Cyprus Interaction Lab [CIL] at the Cyprus University of Technology and the Research Center on Interactive Media, Smart Systems, and Emerging Technologies in Nicosia [RISE-N]. His research interests focus on the investigation of immersive and embodied learning environments grounded on emerging technologies, for inquiry and problem-based learning. His research interests also focus on teachers' professional development through participatory design models, for supporting teachers' learning on innovative pedagogies and new technologies.

Xiaoqing Gu is a professor of Educational Technology at Faculty of Education, East China Normal University. Her main research interests are learning sciences, learning designs, and CSCL.

Dr. Christian Gütl holds a Ph.D. in Computer Science from Graz University of Technology (TUG) and has received the "venia legendi" for applied computer science in 2009. He is at the Institute of Interactive Systems and Data Science at TUG in Graz, Austria, where he leads the Motivational Media Technologies (MMT) Group. Christian has authored and coauthored in more than 200 peer-reviewed book chapters, journals, and conference proceedings publications. He is involved in numerous organizational and editorial boards as well as program committees. He is the founding member of the global Immersive Learning Research Network (iLRN), managing editor of J.UCS, and coeditor of the International Journal of Knowledge and Learning (IJKL). His research interests include information search and retrieval, e-education, e-assessment, adaptive media technologies, and virtual and augmented reality for learning and knowledge transfer.

Michael Holly is a developer and researcher at the Institute of Interactive Systems and Data Science at Graz University of Technology focusing on designing and development virtual reality and physics simulations. He is development lead at the project Maroon, an interactive virtual physics laboratory. His aim is to provide illustrations of physical phenomena in order to give people a deeper understanding of physics.

Christopher D. Hromalik in additional to being a professor at OCC, Mr. Hromalik is a Ph.D. candidate in Instructional Design, Development, and Evaluation at Syracuse University. His research focuses on self-regulated learning, online learning, language instruction, and Universal Design for Learning in community college contexts.

Dr. Mina C. Johnson-Glenberg is a cognitive psychologist, 4D thinker, and entrepreneur. Please visit the website of the spin-out company: www.embodied-games.com

Johannes Kopf is a computer science student and researcher at the Institute of Interactive Systems and Data Science at Graz University of Technology with a focus on the development of VR experiences. He is an assistant at several courses and founding member of the organization “Game Dev Students Graz”, where he contributes with his profound experience in game development. Johannes is also one of the 20 selected members of the Circle of Excellence Graz in the year 2019.

Dr. Tiffany A. Koszalka research focus is studying the integration of learning, instruction, and technologies in instructional and learning environments. She has worked in corporate, higher education and K-12 environments exploring the use of educational technologies for teaching and learning.

Dr. Rita Kuo is an Instructor in the Department of Computer Science and Engineering, New Mexico Institute of Mining and Technology (New Mexico Tech). Her research interests include e-learning, computerized adaptive testing, computerized item generation, cognitive theory, intelligent agent, mobile learning, and game-based learning. She is the associate editor of Technology for Education and Learning since 2014. She has been the track coordinator of ICALT 2018 (the 18th International Conference on Advanced Learning Technologies) Track 7: Technology-Enhanced Science, Technology, Engineering and Math Education (TeSTEM) and sub-conference chair of Joyful Learning and Society (JL&S) in GCCCE 2018 (the 22nd Global Chinese Conference on Computers in Education). She has also been the publication chair of the 4th International Conference on E-Learning and Games (Edutainment 2009) and 1st International Symposium on Smart Learning Environment (SLE 2012), and the editorial advisory board of the Handbook of Research on Learning Culture and Language via ICTs: Methods for Enhanced Instruction. Moreover, she has been reviewers for many journals, e.g., Springer’s Transactions on Edutainment, Computers in Human Behavior (SSCI), International Review of Research in Open and Distance Learning (SSCI), Journal of Internet Technology (SCI), and International Journal of Distance Education Technologies (EI).

Andreas Lanitis is a Professor, at the Department of Multimedia and Graphic Arts, Cyprus University of Technology and the Director of the Visual Media Computing Research Lab. He is also the leader of the BIO-SCENT (Biometrics for Smart human-Centred EmergiNg Technologies) Multidisciplinary Research Group of the Research Centre of Excellence RISE (www.rise.org.cy). He received a B Eng in Electronic Engineering (1991) and Ph.D. in Image Processing and Computer Vision (1995), both from the University of Manchester, UK. His research interests are focused on Biometrics and virtual reality applications. He has published more than 140 papers in scientific journals, edited books and conference proceedings. He was the principal investigator or partner in 23 externally funded research projects funded by National or European agencies. Currently, he serves in the editorial Board of IET Biometrics.

Dr. Kimberly A. Lawless is a Professor of Educational Psychology and the Associate Dean for Research at the University of Illinois at Chicago College of Education. Dr. Lawless has published over 150 articles and book chapters, and present her research at international, national, and regional conferences. Her research focuses on learning in technology-rich environments K-20 and post-secondary and professional training in a variety of disciplines. Dr. Lawless' research has been funded by federal grants in excess of $30 million (USA), focusing on teacher professional development, reading and literacy, educational technology, the GlobalEd 2 project, educational simulations, and medical education. Dr. Lawless currently serves as co-principal investigator on the GlobalEd 2 Efficacy Trials grant, the new 2017 GlobalEd 2 Development grant, funded by the US Department of Education's Institute for Education Sciences, and the PI of Project Includes, funded by NSF.

Victor R. Lee is an Associate professor of Instructional Technology and Learning Sciences at Utah State University. He conducts research on wearable technologies in education, Maker education, and recently computing education. Other lines of research have involved science curriculum materials and conceptual change. He completed his doctorate in Learning Sciences at Northwestern University.

Isabel Lesjak is a Software Engineering and Business Management student and researcher at the Institute of Interactive Systems and Data Science at Graz University of Technology, currently focusing on her master's thesis about interactive physics experiments in Augmented Reality. She was invited to conduct research at University of Sydney as a visiting scholar and has previously worked on the initial version of the award-winning virtual reality physics laboratory "MaroonVR". Her research interests include Virtual Reality, Augmented Reality, and Human–Computer Interaction.

Chee-Kit Looi is a Professor of Education in the National Institute of Education, Nanyang Technological University (NTU), Singapore, and Co-Director of the Centre for Research and Development in Learning, NTU. He was the Founding Head of Learning Sciences Lab, Singapore, from 2004 to 2008, the first research center devoted to the study of the sciences of learning in the Asia-Pacific region. His research interests include mobile and seamless learning, and computer-supported collaborative learning. He has served on the editorial boards of the IEEE Transactions in Learning Technologies, International Journal of AI in Education, International Journal of CSCL, and Journal of the Learning Sciences. He is the President of the Global Chinese Society on Computers in Education.

Xi Lu is a doctoral candidate in the Instructional Systems and Learning Technologies program at Florida State University. Working with her advisor (Dr. Shute), her current research interests focus on designing and developing optimal learning supports to facilitate STEM learning in digital interactive environments.

Zhong-Xiu Lu received his BA degree in information management from Chung Yuan Christian University in Taiwan in 2015 and continued to complete his MBA degree in 2017. Recently, he comes to Canada for studying the Master of Science in Information Systems (MScIS) at Athabasca University and participating the research on designing role-playing quest in an existing educational game in Prof. Maiga Chang's research group. The experience grants him in-depth knowledge and understanding of game-based learning and assessment. The background in information management allows him to quickly understand the concepts of new information technologies and the user requirements in application development. The rich experience of playing games provides him the advantages in the design of game world and quests for educational games.

Despina Michael-Grigoriou is an Assistant Professor at the Department of Multimedia and Graphic Arts of Cyprus University of Technology, and the founding director of the Microsoft Computer Games and Emerging Technologies Research Lab–GET Lab (http://getlab.org), established with seed funding from Microsoft. Despina is also the leader of Visual Science Research Pillar of RISE Research Centre on Interactive Media Smart Systems and Interactive Technologies and she leads within the centre the multidisciplinary research group on Virtual Reality of Well-being. She is a Senate member and coordinates, on behalf of her university, the inter-university postgraduate programme "MSc in Design and Development of Computer Games and Interactive Technologies". Before joining CUT, she was a postdoctoral researcher at EVENT Lab, University of Barcelona (2011), which specializes in experiments within Virtual Reality systems and she held the position of Lecturer (2009–2011) at the University of Nicosia. She received her Ph.D. in Computer Graphics in 2010 from University of Cyprus. She has received several awards and distinctions including Anita Borg Scholarship awarded by Google (2008); nomination of her Ph.D. dissertation for the Best Ph.D. Thesis Award of the Eurographics Association (2011); and two best papers awards (VSMM 2014 and VS-Games 2014). Her research interests focus on Virtual Reality with emphasis on well-being. Despina participated in a number of European and locally funded projects. She is the principal investigator and the deputy scientific coordinator of the H2020-TEAMING RISE project, while she is currently participating in two other H2020 projects. She has been involved in more than ten other funded research projects in the areas of Computer Graphics and Virtual Reality.

Mr. Yuri Pavlov is a doctoral student in Instructional Design, Development, and Evaluation at Syracuse University. His research focuses on student engagement, motivation, and interests in higher education.

Dr. Johanna Pirker is a computer scientist focusing on game development, research, and education and an active and strong voice of the local game development community. She has lengthy experience in designing, developing, and evaluating games and VR experiences and believes in them as tools to support learning, collaboration, and solving real problems. In 2011/12, she started researching and developing VR experiences at Massachusetts Institute of Technology. At the moment, she teaches game development at TU Graz and researches games with a focus on AI, HCI, data analysis, and VR technologies. Johanna was listed on the Forbes 30 Under 30 list of science professionals.

Seyedahmad Rahimi is a doctoral candidate at Florida State University in the Instructional Systems and Learning Technologies program. He is currently working with Dr. Valerie Shute as one of her Research Assistants on several research projects. His research interests include game-based learning and stealth assessment in STEM learning games, and measuring and fostering twenty-first-century competencies (e.g., creativity) in digital games.

Dr. Mary Beth Rosson is a Professor and Associate Dean of Graduate and Undergraduate Studies, in the College of Information Sciences and Technology (IST) at the Pennsylvania State University. Rosson also co-directs the Computer-Supported Collaboration and Learning Lab. Prior to joining Penn State in 2003, she was a Professor of Computer Science at Virginia Tech for 10 years, and a Research Staff Member at IBM T. J. Watson Research Center for 11 years. Rosson received her Ph.D. in cognitive psychology from the University of Texas at Austin in 1982. She is internationally known for research and education in human–computer interaction, participatory and scenario-based evaluation and design methods, computer-supported collaborative learning, and end user development. In recognition of her research accomplishments, Dr. Rosson was elected as Distinguished Scientist of the Association for Computing Machinery and is a member of the SIGCHI Academy.

Dr. Marina Shapio background is in Science Education Research (Chemistry) and Learning Technologies. Her research interests are implementing active learning technologies, such as game-based learning environments, virtual, and augmented reality software into undergraduate college chemistry curricula in order to facilitate methods for active and experiential learning, particularly in the context of lecture settings where students are often passive learners. Currently, Dr. Shapiro is Lecturer of Chemistry at California State University, Bakersfield where she teaches General Chemistry, Foundations of Analytical Chemistry, Biochemistry, and Food Science lecture and laboratory courses.

Valerie Shute is the Mack & Effie Campbell Tyner Endowed Professor in Education in the Department of Educational Psychology and Learning Systems at Florida State University. Before coming to FSU in 2007, she was a principal research scientist at Educational Testing Service, involved with basic and applied research projects related to assessment, cognitive diagnosis, and learning from advanced instructional systems. Her general research interests hover around the design, development, and evaluation of advanced systems to support learning of knowledge, skills, and dispositions. Her research has resulted in numerous grants, journal articles, books, chapters in edited books, a patent, and several recent books.

Kalliopi-Evangelia Stavroulia is a Ph.D. candidate at the Department of Multimedia and Graphic Arts of Cyprus University of Technology. She holds an MSc in the Design and Development of Computer Games and Interactive Technologies from Cyprus University of Technology and University of Cyprus (2016). She also holds a Master of Arts in Education (Education Sciences) with distinction from Roehampton University of London and The Higher School of Pedagogical and Technological Education-ASPETE (2010). She graduated in 2006 from Panteion University of Athens with a degree in International and European Studies. Her research interests focus on the domain of new technologies and specifically in the use of virtual reality, serious games, and simulations in the field of education of any educational level. She has also been involved in research projects on these topics, she has attended and participated at workshops, seminars, and conferences and has published her work in conferences and journals related to this specific area.

Na Sun is a Ph.D. candidate in the College of Information Sciences and Technology at Pennsylvania State University, under the supervision of Dr. Mary Beth Rosson in the Human Computer Interaction Lab. Her dissertation focus is online community building for distance learners in lieu of enhancing students' identity and ties visibility. In particular, she explored the social needs and practices to connect online students beyond class encounters using visualizations. More generally, she is interested in social computing research that aims to enhance social connectedness and promote open education opportunities. Before joining Penn State, Na Sun graduated from East China Normal University with a bachelor's degree in computer science.

Yun Wen is an Assistant Professor of Learning Sciences and Technologies at the National Institute of Education (NIE) in Singapore. She obtained her Ph.D. from NIE and completed her Postdoc at the Computer-Human Interaction in Learning and Instruction (CHILI) Lab in EPFL, Switzerland. Her areas of expertise are Computer-supported Collaborative Learning, Computer-assisted Language Learning, and Learning Design.

Mary K. Wilhelm-Chapin in additional to being an Instructional Designer at SUNY Cortland, Ms. Wilhelm-Chapin is a doctoral student in Instructional Design, Development and Evaluation at Syracuse University. Her research focuses on features of multimedia learning resources that enhance learners deep understanding of course content.

Telmo Zarraonandia holds a degree in Computer Science from the Universidad de Deusto and a Ph.D. in Computer Science from Universidad Carlos III de Madrid where he is currently an associate professor. He is a member of the LAB DEI research group (dei.inf.uc3m.es) focused on the design of interactive systems applied to different domains such as education, emergency and crisis management, or cultural heritage. His research interests include technologies to support education and learning, videogame design, mixed reality environments and interactive systems. He has been visiting researcher at the Universidad Federal do Rio de Janeiro (UFRL) and at the Universitá degli Studi di Salerno (Italy). He has published several scientific papers in international journals and conferences related to the field of computer supported education and interactive systems.

Ms. Lili Zhang is a doctoral student in Instructional Design, Development, and Evaluation at Syracuse University. Her research focuses on the integration of technologies to facilitate learning and provide students with personalized learning experiences. She has worked in corporate, research institute, and higher education environments designing online courses, conducting evaluation projects, and examining the effectiveness of educational technologies.

Chapter 1
Learning in a Digital World: An Introduction

Paloma Díaz and Andri Ioannou

1 Introduction

Learning, as the act, process, or experience of gaining knowledge, skills, and attitudes happening throughout the lifetime of a human is unavoidably influenced by the advancement of Information and Communication Technologies (ICTs). ICTs are more than tools. As posited by Luciano Fioridi in his "Onlife Manisfesto" (Floridi, 2015), our daily experiences in a hyperconnected and digital society shape the way we interact with others and with our environment, and the way we perceive ourselves and reality. These changes in our behavior and perception have a clear impact on our expectations about learning and the role of interactive media in supporting learning. In fact, ubiquitous, social and mobile computing, virtual, augmented and mixed reality, interactive surfaces and spaces, robotics, Internet of Things (IoT) tools and serious games promise unique teaching and learning opportunities in dealing with the educational challenges of the twenty-first-century society.

The often-called twenty-first-century educational challenges include, among others, how to support hyperconnected people to develop skills such as problem solving, creativity, critical thinking, collaboration and communication (Binkley et al., 2012)—skills that people need for work, citizenship, and self-actualization in the twenty-first-century (Dede, 2010). Many of these skills have been around for decades if not centuries, but the way we acquire and apply them has dramatically changed

---

P. Díaz (✉)
Interactive Systems Group DEILAB, Universidad Carlos III de Madrid, Avda de la Universidad 20, 28911 Leganés, Madrid, Spain
e-mail: pdp@inf.uc3m.es

A. Ioannou
Cyprus Interaction Lab, Department of Multimedia and Graphic Arts, Cyprus University of Technology, 30 Archbishop Street, 3036 Limassol, Cyprus
e-mail: andri.i.ioannou@cut.ac.cy

Research Center on Interactive Media, Smart Systems and Emerging Technologies (RISE), Nicosia, Cyprus

P. Díaz et al. (eds.), *Learning in a Digital World*, Smart Computing and Intelligence, https://doi.org/10.1007/978-981-13-8265-9_1

due to our pervasive relationship with ICTs that are making our world more global and immediate. For instance, collaboration has always been valued as an important interpersonal skill in education, but current frameworks of collaboration are relying upon complex technology-mediated environments of distributed intelligence in which people from different walks-of-life and countries need to work together (Dede, 2010). These new contexts require individuals with new attitudes and skills to be able to deal with additional issues provoked by distant, multidisciplinary, and multicultural relationships. In an experience reported in Díaz, Acuña, Aedo, and Ocker (2011), teams of students from Universidad Carlos III de Madrid joined the PSU Partially-Distributed Project (Ocker, Rosson, Kracaw, & Hiltz, 2009) to collaboratively engage in web-design with several teams located around the world. This kind of collaboration forced to develop international, multidisciplinary and multicultural communication skills, not typically practiced in collaborative learning tasks where you know all your mates and you can easily distribute effort, negotiate and manage conflicts. Another relevant skill is that of *learning to learn*, focused on the need to prepare citizens for lifelong learning through active engagement with the information society, collaboration with others, problem solving and creative thinking. ICTs can support the development of these skills by enabling affordable simulations of real-world problems, collaborative learning environments, or multi-user critical thinking and social creativity tools.

There is a lot of expectation around emerging technologies to continue to advance teaching and learning. There are now many products and prototypes available, but at the same time, lack of research to inform teachers, learners, education managers, and even parents on best technologies for specific learning tasks, considering also ergonomic and economic perspectives (Bricken, 1991). When selected wisely, interactive technologies can support learning experiences in line with the learners' needs and expectations as well as the requirements of the educational context. This challenge can be faced when learning technologies are envisioned as sociotechnical ecosystems made up of people, contexts, and digital tools. Thus, their development should be addressed from a multidisciplinary perspective combining knowledge of different disciplines including education, design, human-computer interaction, or computer science among others.

Today, the variety of available technologies to support learning and teaching is so broad that deciding what to use, how to integrate them in the classroom, and what outcomes to expect is a complex issue. A technologically supported learning environment is not effective by itself; it must be adopted by educators, learners, and other stakeholders considering their goals, attitudes and expectations. This book aims at guiding this decision by providing discussions on the learning affordances and the challenges that interactive technologies pose through several experiences in developing and integrating them in varied educational settings. In the chapters of this book, scholars from different disciplines analyze complementary issues concerning the integration of interactive technologies in various educational settings, while they address theoretical, pedagogical, design, and technical considerations. There are plenty of books, papers, and reports on the use of interactive technologies for education, but what makes this book different is that the contributors focus on multidisciplinary research in this area, aiming to shed light at how interactive media can be used to promote the so-called twenty-first-century skills (Binkley et al., 2012) in formal, non-formal, and informal educational settings.

The study of learning in the digital world is by no means a trivial task. Unfolding the interplay of technology and learning is difficult to achieve due to the many factors involved (Lowyck, 2014). This is the reason why educational technology is a constantly evolving discipline concerned with advancements in technology in accordance to the evolving learners' needs and expectations regarding technology. The contributors in this book adhere to beliefs that interactive media can be used to address these needs and expectations and to develop engaging learning experiences in all educational settings, tearing down time, space, social and economic barriers.

2 Book Goals and Structure

The goal of this book is to extend the interest in interactive media for learning and to provide a theoretical and empirical basis for the use of various technologies in supporting the development of the twenty-first-century skills such as collaboration, problem solving, critical thinking, and creativity (Binkley et al., 2012). To achieve this goal, the book brings together a group of international scholars who approach research questions on technologically mediated learning from a variety of theoretical and methodological perspectives, in several different types of educational contexts, and from different participant perspectives (students and teachers). The 15 chapters included herein, in addition to the introduction chapter, present various experiences from developing and integrating interactive technologies in varied educational settings with a view to offering readers a better and more comprehensive understanding of their "benefits and affordances, trade-offs and limitations".

All the chapters of the book aim at exploring the use of interactive media in promoting learning. In some cases, cutting-edge technologies that provide new learning opportunities, such as embodied learning, are analyzed while other chapters deepen on the use of perhaps less sophisticated technologies yet able to support crucial learning outcomes like collaboration and critical thinking. Other chapters focus on novel approaches to develop, integrate, and use interactive media in various learning contexts. Overall, the chapters discuss pedagogical issues and affordances of specific interactive technologies for learning. The authors analyze the benefits of these technologies but also limitations and challenges in their integration, they provide empirical support for their utility in dealing with specific learning issues and teaching methods and they introduce useful guidelines and heuristics for designing technology-enhanced teaching and learning.

3 Book Contents

3.1 Part I: Theoretical and Empirical Findings on the Integration of Interactive Technologies

The first part of the book comprises eight chapters offering theoretically grounded perspectives on the integration of interactive media in various educational settings. The chapters aim to promote understanding of why and how to use interactive technology while raising questions for the readers with respect to the values, trade-offs, contributions, and limitations of using technology in the educational setting.

Chapter 2, “Prompting Deep Learning with Interactive Technologies: Theoretical Perspectives in Designing Interactive Learning Resources and Environments” by Tiffany A. Koszalka, Mary K. Wilhelm-Chapin, Christopher D. Hromalik, Yuri Pavlov, and Lili Zhang, puts the focus on a key problem: the need to promote deep learning, from memorizing contents and test-passing to acquiring and applying key attitudes, knowledge, and skills. The authors provide a solid discussion on how different interactive technologies might support learners in and in deep thinking and learning as they interact with content. The goal is to understand how technology can be used to support independent learners in solving real-world problems through the lens of generative learning theory (Wittrock, 1974), cognitive flexibility theory (Spiro, Coulson, Feltovich, & Anderson, 1988), and reflection theory (Zimmerman, 2002). Starting with a sound review of the state of the art, the authors summarize the affordances of current technologies (e.g., simulations, educational games, virtual worlds, augmented reality). Their aim is to provide several design guidelines for learning resources and environments that enhance deep learning via interaction and engagement with content. The chapter ends by describing two examples on how to turn static and dynamic resources into valuable assets for deep learning.

Chapter 3, “Creating Dialectics to Learn: Infrastructures, Practices, and Challenges” takes a similar approach to analyze how interactive media can promote twenty-first-century skills like critical thinking and problem solving (Binkley et al., 2012). In this chapter, John M. Carroll, Na Sun, and Jordan Beck discuss the role of dialectical constructivist learning as an endogenous constructivism approach (O’Donnell, 2012) in preparing critical thinkers by pushing them to “articulate multiple perspectives and then comparatively debate, deconstruct, and analyze their strengths and weaknesses to synthesize new perspectives”. The authors frame “debate” as a core pedagogical activity central to modern dialectical constructivism and explore how different technological tools and platforms support this method. Different experiences are presented in the chapter: technology appropriation (using Piazza) and technology development (the Critical Thinker) to support controlled learning activities within a specific course and analyzing in-the-wild debates in Kialo—an online peer production community. The chapter summarizes the findings of these experiences in terms of issues, approaches, and lessons learnt that can help readers to understand why and how to use interactive technologies to integrate dialectics as a learning activity.

Who hasn't played "Tens go fish" to learn how to add? Wasn't it more engaging than just adding numbers in the blackboard? Digital games, often called serious games, have been around in the educational arena for the last three decades. They have been traditionally used in many classrooms to take profit from the intrinsic motivation associated with ludic activities and intersperse cognitive challenges that support learning. At the same time, gameful design and gamification have been utilized to bring game elements and fun into other types of learning activities around technology (Ioannou, 2018). It is not only that games and gamification are fun, but they are a way to learn and practice rules, social interactions, and interpersonal skills. However, just like with any other technology, digital games are just a tool and they do not guarantee effective learning. In Chap. 4 "Supporting Learning in Educational Games: Promises and Challenges", Valerie Shutte, Seyedahmad Rahimi, and Xi Lu analyze types of learning supports in digital games including supports for reflection, modeling, advice, collaboration, feedback, and multimodality among others. In the second part of the chapter, the authors introduce their own educational game—Physics Playground—which supports students in acquiring physics competences. The chapter provides an in-depth description of the iterative process followed to design a game that meets the different needs identified in usability and experimental studies. The details of the design cycle as well as the valuable instructional resources presented in this work can help readers to understand the design process of a serious game as an incremental process focused on people (teachers, learners and other stakeholders) and their goals.

Virtual Reality (VR) is without a doubt one of the technologies that has created high expectations in education. It has been used in the last 20 years mainly in lab experiments and simulations, but now that immersive VR devices are becoming commercially available and they are starting to enter our living rooms, new opportunities about their application in formal, non-formal, and informal learning emerge. Chapter 5, under the title "The *Necessary Nine*: Design Principles for Embodied VR and Active STEM Education", Mina C. Johnson goes deeper into two important affordances of virtual reality: the sense of presence into the virtual world that might generate engagement and attention and the agency of manipulating objects in a 3D space that might improve active learning by relying upon the main tenets of embodied learning (Wilson, 2002). The authors introduce some terms, affordances, and associated pedagogies as well as a set of design guidelines in the form of heuristics that might guide readers in deciding how to create quality content for immersive VR educational experiences. The chapter describes two examples of design of VR educational experiences, where natural interaction is used to improve learning by enabling students to use their bodies to interact with the environment.

And what if the learning devices are embedded into what we wear? Can I use my watch, glasses or clothes to teach or learn? In Chap. 6, "A Broad View of Wearables as Learning Technologies: Current and Emerging Applications," Victor R. Lee and R. Benjamin Shapiro discuss several uses of wearable devices to support teaching and learning activities. In the first part of the chapter, the authors analyze a number of experiences reported in the literature organized into four groups: experiences that support personal expression basically through smart textiles; experiences that integrate digital information into social interactions using devices like smart badges; experiences that support role-play in participatory simulations, and, finally, experiences that provide just-in-time notification and feedback using smart watches and augmented reality glasses. The chapter ends by introducing two projects from the authors in which wearables are used in a more visionary way: (i) to get feedback from bodily experiences of humans, mainly to visualize activity tracks and enable discussion around healthy habits, and (ii) to get feedback from pets, to gain more insight into how pets experience the world. This review chapter provides an interesting glance at some of the possibilities that highly portable technology might bring to formal, non-formal, and informal education and might inspire teachers and educators to envision innovative learning activities.

The last three chapters of Part I present studies and reviews of interactive technologies used in education with a view to provide useful hints to designers and developers on current tendencies and uses. In Chap. 7, “Promoting Online Learning Community with Identity Transparency,” Na Sun, Mary Beth Rosson, and John M. Carroll examine social interaction as a key issue to guarantee retention in online learning. Online learning has gained momentum especially due to the increasing need for lifelong learning in the twenty-first century. Though initially online learners are mainly attracted by the fact of acquiring new knowledge or skills wherever and whenever they want, studies demonstrate that social interaction is a key issue to guarantee retention. In this chapter, the authors introduce three empirical studies, two qualitative and one quantitative, aiming to understand how social interaction is perceived and valued in online learning communities. Through semi-structured interviews with teachers and learners and quantitative investigation of two key constructs—the sense of community and the community collective efficacy—the authors present valuable findings that can be used by online teachers and developers of computer-supported collaborative learning systems. Some of the valued features identified, for example, identity transparency, live sessions, continuous social interaction and immediate feedback, suggest the need to think about online learning systems as structures to support not only content delivery and interaction but also, fluid and richer human-human interaction.

In Chap. 8, “Embodied Learning in a Digital World: A Systematic Review of Empirical Research in K-12 Education”, Yiannis Georgiou and Andri Ioannou discuss the notion of embodied cognition and summarize empirical findings from research on technology-enhanced embodied learning environments targeting student learning outcomes. The review revealed positive outcomes linked to technology-enhanced embodied learning—mainly cognitive outcomes in the domains of science, technology, engineering, and mathematics (STEM). The authors provide insightful direction for future research and practice in the field with respect to domain (e.g., beyond STEM), learning outcomes (e.g., consideration of affective, and psychomotor domains), research methodology (e.g., more in situ measurements and experimental designs), and design issues (e.g., integration research addressing tools for embodied learning, classroom orchestration, technological setup, learning design). The review sets the bases for further research in the field of technology-enhanced embodied learning.

In Chap. 9, authors Yu Wen and Chee-Kit Looi provide an overview of the literature on Augmented Reality (AR) uses in education in their chapter “Review of Augmented Reality in Education: Situated Learning with Digital and Non-digital Resources”. The authors propose a categorization of applications based on a matrix that proposes two dimensions: type of learning supported (surface vs. deep knowledge) and type of experience supported (context-independent vs. context-aware). With this matrix, they categorize different contributions to try to identify fields in which AR is being used, the theoretical basis for the design of such experiences and pedagogical approaches followed. In this way, the chapter provides a glance into the current state of AR uses in educational settings.

3.2 Part II: Theoretical and Empirical Findings on the Integration of Interactive Technologies

The second part of the book collects several contributions more related with specific experiences and examples of using interactive technologies to support teaching and learning. Chapter 10, “Virtual Reality Environments (VRLEs) for Training and Learning” by Kalliopi-Evangelia Stavroulia, Maria Christofi, Telmo Zarraonandía, Despina Michael-Grigoriou, and Andreas Lanitis describes several potential uses of VR in education from the point of view of the learners as well as teachers. A very interesting contribution of this chapter is the use of VR at the Cyprus University of Technology to induce empathy as a learning goal (i.e., to deal with addictions, or improve social behavior in multicultural environments) and to help teachers put themselves into their student’s shoes, which can be considered as an important skill in our globalized world (i.e., perceptive taking). The chapter ends by reviewing some of the end-user tools developed at Universidad Carlos III de Madrid that allow non-technical users to create their own educational VR worlds without requiring any programming skills.

Chapter 11, “MaroonVR—An Interactive and Immersive Virtual Reality Physics Laboratory” describes an interesting example of using an interactive learning tool in the STEM field. Johanna Pirker, Michael Holly, Isabel Lesjak, Johannes Kopf, and Christian Gütl describe the architecture of the system and the iterative design process they follow to highlight several benefits and potential limitations that are summarized as design principles which could also be translated to other domains. Such principles include heuristics like improving concentration through immersion, setting objectives for self-regulated learning, supporting different forms of immersion, allowing exploration and new forms of interaction, including social interaction.

In Chap. 12, “Designing Learning Activities Using Different Augmented Reality Applications for Different Learning Subjects for Elementary Students”, Sie Wai Chew and Nian-Shing Chen analyze how AR can be used to promote three instructional models: collaborative learning, inquiry-based learning and situated learning. The authors describe two experiences of designing and evaluating specific tools for learning about science and culture, respectively. These two experiences can help other educators to envision how to design AR learning tools for integration in their classroom.

Digital games are revisited in Chap. 13, "Teaching Technology Design: Practicing Teachers Designing Serious Educational Games" from a different perspective. This is not a study on the utility of serious games but rather the description of experience on how to engage teachers in the design of games. Leonard A. Annetta and Marina Shapiro use design thinking techniques to sparkle creativity and provide a certain process flow. In a study of practicing K-12 science and instructional technology teachers designing serious games, this chapter illustrates how teaching and learning design changes how teachers think.

Student motivation is a key issue in online learning. In Chap. 14 "Student and Teacher's Perceptions Toward the In-game Card as Educational Reward (ICER) Moodle Plug-in," Rita Kuo, Maiga Chang, Zhong-Xiu Lu, and Cheng-Li Chen introduce a Moodle plug-into use in-game cards as educational rewards. Teachers can assign card rewards to specific learning tasks and then students can compete with their peers using their cards in an online Trading Card Game (TCG). In an empirical evaluation, the authors analyze the perceived importance of educational rewards and the perceived ease of use under four moderators (gender, role, experience in Moodle, and experience in TCG). The authors present several expected and unexpected findings that might illustrate the benefits and design challenges of integrating this kind of educational reward.

Chapter 15, by Scott W. Brown and Kimberly A. Lawless reports on "The GlobalEd2 Project: Interdisciplinary Simulations Promoting Students' Socio-scientific Literacy". This is a PBL curriculum intervention that combines face-to-face and online learning, engaging students in interdisciplinary learning on science and written argumentation. The chapter details how GlobalEd 2 has successfully evolved over the past 15 years with documented learning outcomes on science and civics, written argumentations, interest in science, scientific literacy, and global citizenship. In terms of technology, the GlobalEd 2 communication and research platform is the backbone of the simulation which allows hundreds of students to connect and engage in negotiation, while other tools such as tables, the teacher's web portal are also needed technological means supporting the implementation. The chapter integrates findings from a series of GlobalEd 2 research studies as well as research on PBL, providing a guide for developers and educators planning to employ technology-based simulations in their classrooms.

Finally, the last chapter of the book, Chap. 16, "Designing a Collaborative Visualization-Based Learning System for Problem Solving to Transform the Classroom Ecosystem" by Huiying Cai and Xiaoqing Gu presents the semantic diagram tool as a driver to transform the interactive sub-ecosystem between teacher and students as well as students in a group, during problem solving. The semantic diagram tool is used to change the roles of teachers and students and to support more active problem solving. The tool pushed teachers to move from sheer knowledge disseminators to learning facilitators by giving more relevance to student activities.

4 Book Audience

The book compiles experiences with different interactive technologies with a view to provide a comprehensive perspective on the use, potential utility and value of interactive technologies in supporting teaching and learning. The primary book audience is researchers, teachers and students (e.g., graduates in teacher preparation programs) and other stakeholders in the fields of education, educational technology, and ICTs in education.

The book is addressed to anyone interested in having a glance at how interactive technologies can be used to support key educational challenges. Chapters are written in a clear and understandable language making them accessible not only to educational researchers but also to educational practitioners. The book chapters do not only focus exclusively on technology uses in educational settings but also provide a broader view of the impact and affordances of technology to improve the learning process.

5 Discussion and Future Directions

We would like to sincerely thank the authors of the 15 chapters presented here. Because of their work, we now know more about the interplay of interactive media, pedagogy, and learning as well as the affordances of various media for formal, non-formal, and informal educational settings. This book compiles contemporary and multidisciplinary research in this area, with the goal of arousing other investigators to contribute to the growing empirical literature on interactive media for learning.

The chapters in this book explore research question on technologically mediated learning from a variety of theoretical frameworks, including generative learning theory, cognitive flexibility theory, and reflection theory. Key pedagogical approaches are presented (e.g., constructivist dialectics, problem-based learning) in line with interactive media technologies. Current technologies (e.g., simulations, virtual and augmented reality, wearables) are utilized and discussed in different types of learning contexts, and from different participant perspectives (students and teachers). Their use appears to be instrumental for the learning process with evidence of learners' gains in knowledge, attitudes, and skills. Design issues are of concern in all chapters; a few design hints, principles, guidelines and heuristics can be distilled from the included studies.

Nonetheless, there is still a dearth of systematic research in this area. For certain, the relevant questions still to be answered are many, and the methodologies appropriate for answering those questions are varied since we are living in a rapidly changing world where technologies are not only pervading all daily activities, but also changing the way we perceive the world and ourselves. Accordingly, we hope this book will spark more discussion and reflection on the issues raised by the authors and encourage other researchers to take on the task of rigorously studying the factors involved in the design and use of interactive media for learning. That said, below we offer questions for prospective researchers to consider:

- *How can we open education to integrate all the stakeholders (educators, learners, managers, families, communities) in a more active way?* This is a broad challenge that can be to some extent, supported by interactive technologies, particularly pervasive and social computing. Yet, as illustrated in many of the chapters of this book, we also need to encourage all stakeholders to participate in a meaningful, sustainable and affordable way. Research needs to advance in open educational models created and managed by different types of stakeholders. Teachers, educational managers, learners, families, and members of the community can contribute their part to a participatory learning ecosystem. Such ecosystem can be envisioned as a digital knowledge ecosystem, that is, as a "distributed adaptive open socio-technical system for knowledge sharing and management exhibiting properties of self-organization, scalability and sustainability" (Briscoe, 2010).
- *How can we enable non-technical people to appropriate and personalize technology to create their own learning experiences?* This research question is directly related to the idea of scalability and sustainability of digital ecosystems. There are no one-size-fits-all solutions in education, neither solutions that work always and forever. Learning is a complex, evolving and long-term process that depends on personal, sociocultural, and economic factors. We cannot expect that some technology, pedagogical approach or tool will work the same in different educational contexts. Thus, we need to be able to adapt our tools and methods to the specific requirements of each educational context. For that to be possible, we can rely on motivated humans who know the problem, have the passion required to tackle it, but probably lack the technical background to implement a solution. End-user engagement and tools can help to democratize innovation by enabling non-professional software developers to ideate, create, and modify their own learning experiences.
- *How can we use technology to turn every living space into an educational opportunity?* Interactive technologies such as augmented reality, pervasive computing (including wearable and mobile computing), and IoT tools can be exploited to turn every space and moment into a learning experience. Technology is ready and available, what remains is to understand which pedagogical models can be served and mediated by these technologies and how to design useful yet enjoyable learning experiences.
- *How can we promote creativity and authenticity in education through the mean of technology?* Social computing can serve groups of people who connect and interact to co-construct knowledge, driven by their common passion, interest, and goals in a specific domain (Lave & Wenger, 1991). Such communities can foster the authentic knowledge and skills needed for the development of creative outcomes in response to real-world needs. Such communities can only be realized by integrating technologies that allow to overcome critical disparities in terms of location and time and inspire communication and collaboration.

The above list of questions is of course not exhaustive. Instead, it is an initial list of ideas based on the authors' reflections on the included chapters and their own scientific perspectives from research in this area. We are confident that the chapters presented here will contribute to our deeper understanding of interactive media for learning. Taken together, these chapters highlight the many ways in which interactive media can help to shape knowledge, attitudes, behavior, and achievement in all learning settings. The book compiles experiences with different interactive technologies aiming to provide a comprehensive perspective on the use, potential utility, and value of interactive technologies to support teaching and learning.

6 Conclusion

Learning is an extremely broad concept, and this makes it hard to answer the question of what the main factors influencing learning are, and thus to identify technologies and methods that optimize learning (Lowyck, 2014). At the same time, the variety of available technologies is so broad that deciding what to use, how to integrate, and what outcomes to expect is a complex issue. This book aims at guiding this decision by providing not only examples of the use of technologies but also well-grounded discussions on their learning affordances and the challenges they pose. Communication between scholars of different disciplines, including education, design, human–computer interaction, computer science can ensure that learning theories, models, and principles will guide the design of technological tools with best possible value for learning. Using systematic, theoretically grounded, and empirically sound research, we can build on the work presented in this special issue to move the field forward. To sum up, we perceive the following most important features and benefits of the book:

- It compiles the experiences of international scholars on the use of interactive media for learning.
- Key technologies like augmented and virtual reality, serious games or ubiquitous computing are analyzed in specific educational contexts demonstrating their utility and value.
- It focuses on teaching and learning methods and practices linked to the integration of specific technological tools.
- It presents multidisciplinary projects aimed at a variety of learning outcomes, e.g., science learning, critical thinking skills.

The book chapters provide a broader view that does not focus on technology characteristics but rather, on the impact and added value of technology integration in teaching and learning. The book is addressed to researchers, educators, and other stakeholders in education interested in having a glance at how interactive technologies can be used to support key educational challenges. Overall, the book is expected to shed light and raise academic discussions on the interplay of interactive media and learning in formal, non-formal, and informal educational settings—how learning gains emerge and are documented, and how the use of interactive media relates to important behavioral, motivational, and achievement outcomes.

Acknowledgements This research has been partly supported by the project that has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 739578 (RISE—Call: H2020-WIDESPREAD-01-2016-2017-TeamingPhase2) and the Government of the Republic of Cyprus through the Directorate General for European Programmes, Coordination and Development.

References

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., & Rumble, M. (2012). Defining twenty-first century skills. In P. Griffin, B. McGaw, & E. Care, (Eds.), *Assessment and teaching of 21st century skills* (pp. 17–66). Australia: Springer. https://doi.org/10.1007/978-94-007-2324-5.

Bricken, M. (1991). Virtual reality learning environments: Potentials and challenges. *ACM SIGGRAPH Computer Graphics, 25*(3), 178–184.

Briscoe, G. (2010). Complex adaptive digital ecosystems. In *Proceedings of the International Conference on Management of Emergent Digital EcoSystems* (pp. 39–46). ACM.

Dede, C. (2010). Comparing frameworks for 21st century skills. In J. A. Bellanca (Ed.), *21st century skills: Rethinking how students learn.* Solution Tree Press.

Díaz, P., Acuña, P., Aedo, I., & Ocker, R. (2011, April). The impact of working in Partially Distributed Teams in a Web Design course. In *2011 IEEE Global Engineering Education Conference (EDUCON)* (pp. 358–365). IEEE.

Floridi, L. (2015). The online manifesto: Being human in a hyperconnected era. Cham, Heidelberg, New York, Dordrecht, London: Springer.

Ioannou, A. (2018). A model of gameful design for learning using interactive tabletops: Enactment and evaluation in the socio-emotional education classroom. *Educational Technology Research and Development,* 1–26.

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

Lowyck, J. (2014). Bridging learning theories and technology-enhanced environments: A critical appraisal of its history. In *Handbook of research on educational communications and technology* (pp. 3–20). New York, NY: Springer.

Ocker, R. J., Rosson, M. R., Kracaw, D., & Hiltz, S. R. (2009). Training students to work effectively in Partially Distributed Teams. *ACM Transactions on Computing Education, 9*(1), Article 6.

O'Donnell, A. M. (2012). Constructivism. In K. R. Harris, S. Graham, T. Urdan, C. B. McCormick, G. M. Sinatra, & J. Sweller (Eds.), *APA educational psychology handbook, Vol 1: Theories, constructs, and critical issues* (pp. 61–84). Washington, DC: American Psychological Association.

Spiro, R. J., Coulson, R. L., Feltovich, P. J., & Anderson, D. K. (1988). *Cognitive flexibility theory: Advanced knowledge acquisition in ill-structured domains*. Technical Report No. 441.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review, 9*(4), 625–636.

Wittrock, M. C. (1974). Learning as a generative process. *Educational Psychologist, 11,* 87–95.

Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory into Practice, 41*(2), 64–70. https://doi.org/10.1207/s15430421tip4102_2.

Chapter 2
Prompting Deep Learning with Interactive Technologies: Theoretical Perspectives in Designing Interactive Learning Resources and Environments

Tiffany A. Koszalka, Mary K. Wilhelm-Chapin, Christopher D. Hromalik, Yuri Pavlov and Lili Zhang

1 Introduction

With the emergence of new types of interactive technologies, formal and informal educational resources and environments are being inundated with opportunities for learners to interact with content in multiple ways through a variety of digital materials and experiences. Newer technologies receiving much attention in recent educational literature include simulation-like environments, virtual reality, and augmented reality. Access to these experiences has opened up from the stand-alone computer to include networks (internet), tablets, mobile technologies, peripherals, and even robots. Each access device adds different affordances and challenges to engage learners in content thinking. Research on these interactive technologies spreads across multiple content domains (e.g., K-12 curriculum, engineering, medicine, sciences, humanities) and responds to a variety of questions about teaching and learning effectiveness; effects on learner perceptions, skills, emotions, and learning outcomes; and

---

T. A. Koszalka (✉) · Y. Pavlov · L. Zhang
Instructional Design, Development and Evaluation, Syracuse University, Syracuse, NY, USA
e-mail: takoszal@syr.edu

Y. Pavlov
e-mail: ypavlov@syr.edu

L. Zhang
e-mail: lzhang16@syr.edu

M. K. Wilhelm-Chapin
State University of New York (SUNY) Cortland, Cortland, NY, USA
e-mail: mary.wilhelmchapin@cortland.edu; mkwilhel@syr.edu

C. D. Hromalik
World Languages Department, Onondaga Community College, Syracuse, NY, USA
e-mail: hromalic@sunyocc.edu; cdhromal@syr.edu

P. Díaz et al. (eds.), *Learning in a Digital World*, Smart Computing and Intelligence, https://doi.org/10.1007/978-981-13-8265-9_2

creation of instructional design principles. New questions are asking whether the use of these technologies are prompting critical thinking and deeper content understanding or inhibiting learning (Garrison & Cleveland-Innes, 2005; Liu & Kaye, 2016; Murray, Pérez, Geist, & Hedrick, 2013). Results are varied and mixed.

A current research theme of particular interest is calling attention to learner–content interaction, specifically unpacking the relationships among interactive technology features and learner–content interaction design (Anderson, 2003; Dondlinger, 2007; Lamb, Annetta, Firestone, & Etopip, 2018). Cummings' team (2015) suggested that learners must be engaged in interactive learning opportunities that allow them to feel connected to the instructional environment and not just as key-pressing spectators. In this context, being connected suggests that learners interacted with technologies in ways that help focus their attention on content. They are prompted to feel like part of the learning situation and feel comfortable in exploring content. They are encouraged to use, share, and display their developing knowledge and they are engaged in reflecting about their own learning goals [self-regulation] and study practices. Such foci, emotions, interactions, collaborations, and reflections prompt learners to reach significantly higher achievement in content learning than those who interact with resources and environments that do not foster this sense of connectedness or provide focused content learning experiences and scaffolds (Bernard et al., 2009). Unpacking thinking and learning mechanisms is important in identifying how to design and incorporate interactive features to support learners in developing content knowledge (Gagné & Briggs, 1996; Reeves, Herrington, & Oliver, 2005).

This chapter begins by summarizing cognitive learning processing differentiating between surface and deep levels. The focus then turns to integration and adaption of technologies in learning environments highlighting poor and good design features aimed at prompting learner interaction, engagement, and reflection. Existing research on generative learning theory, cognitive flexibility theory, and reflective theory provide the basis for proposed guidelines to prompt learner–content interaction resulting in deep levels of processing. Researchers are encouraged to design rigorous studies to contribute to our understanding of how instructional design around technology features affects learner–content interactions toward deep learning.

Connections between technology features and the degree to which they prompt deep learning processing are unclear from current research. As educational technologies advance in their ability to be interactive, research to explore features that prompt learners to engage with the content, particularly at deep levels of processing, is warranted to guide future design and development.

2 Thinking, Learning, and Deep Learning

Learners need to think and act to learn (Biggs, 1989; Wittrock, 1974). The assumption of this chapter is that learning is an ongoing cognitive and activity-based process. Learning processes involve learners actively experiencing, thinking about, and integrating representations (e.g., text, images, sounds, smells, tactile sensations, tastes) of content from resources into their developing knowledge structures (Jonassen, Campbell, & Davidson, 1994; Kolb & Kolb, 2012; Merriam, Caffarella, & Baumgartner, 2007). Resources are content containers (information providers) that can be human, object, or an environment—physical or virtual. Learning resources (and learning environments) however bring a dimension to the learner–content interaction experience that moves content containers into resources that purposively prompt learner physical interaction and mental processing in the support of knowledge development (Koszalka, 2016a).

Although a rather complex behavioral and internal process, simply put, learners start to develop new knowledge, skills, or attitudes by a consciously or unconsciously triggered recalling of what they already know, can do, and or feel, and related types of experiences they have already had (Gagné, 1985). This previously learned knowledge was stored, organized, and integrated within their schema and the trigger identifies disparities or gaps in this current knowledge (Anderson & Pearson, 1984; Rumelhart, 1980).

Guided by their personal mechanisms of learning [like preferences, interests, goals, and abilities], learners then interact and engage with new information to begin generating connections from new information experiences into their existing knowledge structures [schema] to close these gaps (Rumelhart & Norman, 1978, 1981). More and richer sets of connections generated around content suggest a deeper knowledge (Anderson & Pearson, 1984; Grabowski, 2004).

Not all knowledge is in the same domain, e.g., cognitive, affective, psychomotor, nor is learning all at the same level of complexity, e.g., low to high (Anderson et al., 2001; Bloom, 1956; Dave, 1971; Krathwohl, Bloom, & Masia, 1964). Learners take different approaches to learning with the outcomes of learning being closely associated with the chosen approach (Ramsden, 2003). For example, to learn a skill, learners may choose (or be prompted to choose) hands-on practice based on watching a demonstration, whereas when learning new information they may choose (or be prompted to choose) to work through multiple interactions with the information, models and graphics, plus participate in focused thinking-based practices (Ormrod, 2016). The approach a learner chooses and takes can predict the level at which learning occurs.

2.1 Surface and Deep Processing

Learning can occur through surface level processing (low-level thinking) or deep level processing (high-level thinking) depending on learner goals (Biggs, 1989). Learners using surface level processing approaches focus (or are prompted to focus) on the substance of information and generally use low-level recall and memorization techniques (Biggs, 1989; Tagg, 2003). They perceive the learning goal is to study for a test to avoid failure rather than to grasp key concepts and determine how to apply new knowledge (Bowden & Marton, 1998). Thus, surface level learning likely results in few connections among schema. See Table 1.

Table 1 Characteristics of surface and deep thinking processing

Surface level processing	Deep level processing
• Substance of content • Recall and memorization • Goal is to pass the test	• Substance and meaning of content • Self-monitor, correct own thinking • Personal commitment to learning • Reflect on understanding • Pursue multiple perspectives and application of content • Goal is deep understanding

Learners using deep level processing approaches focus (or are prompted to focus) on substance and underlying meaning of content (Biggs, 1989) and actively self-monitor and correct their own thinking during their learning (Elder & Paul, 2009). Deep thinking is activated when learners' engage in applying, analyzing, evaluating, and creating content (Anderson et al., 2001).

Deep level processing is represented by a personal commitment to understand the material that is echoed in activities like reflecting on how individual pieces of information relate to larger constructs or patterns and applying knowledge in real-world situations (Biggs, 1987, 2003; Entwistle, 1981; Ramsden, 2003; Tagg, 2003). Deep learning is also about developing habits to consistently think and reflect, approach new phenomena in thoughtful ways, and see new phenomena from different perspectives in everyday life (Dennis & Vander Wal, 2010; Elder & Paul, 2009; Ramsden, 2003; Tagg, 2003). Deeper comprehension results in the ability to articulate multiple perspectives and uses of content in new ways and different contexts (Jonassen et al., 1994; Spiro, Feltovich, Jacobson, & Coulson, 1992; Vos, van der Meijden, & Denessen, 2011).

The level of processing is also affected by the nature of learning tasks, e.g., content domain, time on-task, learner–content and learner–resource interactions, type and level of learning task, expected outcomes, prompts, and characteristics of resources (Laird, Shoup, & Kuh, 2005). Passey and Hobrecht (2001) found that higher levels of self-study and interaction with learning resources led to higher level performance outcomes, suggesting deeper content knowledge (Bloom, 1956). Deep learning is associated with abilities to retain, integrate, and transfer content knowledge, attitudes, and skills at higher rates (Biggs, 1989; Prosser & Millar, 1989; Ramsden, 2003; Van Rossum & Schenk, 1984).

Thus, if the goal of formal or informal instruction is to foster surface level learning, the design should prompt test-passing goals with the use of memorization and recall learner–content interactions. If the goal is deep content learning, the design of learning resources should prompt activation of prior knowledge and experiences and provide multiple types of learner–content interactions accentuating content-focused engagement [thinking]. "The only capacity we can use to learn is human thinking. If we think well while [actively] learning, we learn well. If we think poorly during learning, we learn poorly" (Paul & Elder, 2007, p. 8).

The characteristics of learning resources can influence a learner's goals and learning (Dick & Carey, 1978; Gagné & Briggs, 1979) and play a role in learners' choices for processing new information (Biggs, 2003; Garrison, Anderson, & Archer, 2001; Littlejohn, 2003). However, it is unclear which features of interactive learning resources and learning environments prompt connectedness and deep learning and which are distracting or detrimental.

3 A Brief Review of Educational Technology Uses and Research

Historically, technology uses in education began as supports for teacher-centered pedagogies, e.g., film, radio, projectors (Reiser, 2001a, b). As more sophisticated technologies like calculators and computers emerged learners became the targeted users (Reiser, 2001a, b). These computer-based resources, however, generally held to teacher-centered approaches that primarily provided small chunks of content and tested for learner recall of that content (Gagné & Briggs, 1996; Ormrod, 2016).

As technology became more powerful with the advent of CD-ROMS, DVD and eventually the internet, features like graphics, sounds, multimedia, and new types of interactions were added and more learner controls and choices were integrated to lend themselves to learner-centered pedagogies (Koszalka & Ganesan, 2004; Reiser, 2001b). These evolving resources offered rich learning environments with a multitude of information, visualizations, interactions, social connections, and prompts to support independent learning. New devices (e.g., tablets, smart phones) now enable learners to interact with these rich environments anytime, anywhere, with any connected resources—human or informational (Koszalka & Ntloedibe-Kuswani, 2010; Li & Wang, 2018).

Today simulations, virtual reality, and augmented reality are rapidly entering into the educational realms. Many are being built upon cognitive models and artificial intelligence offering human-like digital or physical components like avatars and robots to involve and engage learners (Alimisis, 2016; Curto & Moreno, 2016; Girvan, 2018). These technologies provide learners with authentic and immersive environments, context-sensitive triggers proposing to provide help and formative feedback based on learner choices and decision-making interactions, and intellectual, social, physical, and emotional stimuli that immerse learners in rich sensory and often times social learning experiences (Chattopadhyay, Gangadhar, Shankar, & Kasinathan, 2018; Lamb et al., 2018; Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014; Oigara, 2018; Sousa, 2005). Research questions continue to ask how well these rich and interactive technology resources actually prompt learner–content interaction that supports thinking and deep learning.

Guidelines like the Technological Pedagogical Content Knowledge (TPaCK) framework were developed in response to haphazard practices using new technologies in the classroom, questions about the alignment of technologies with pedagogy and content, and questions about the value of technology in learning (Koehler & Mishra, 2009). This framework suggests that certain technologies are best used with specific pedagogies that align most effectively to specific content domains, e.g., science and reading. Integrating pedagogical approaches can foster cognitive presence [thinking about content], reflection, and discourse (Cook-Benjamin, 2018; Garrison et al., 2001) and influence the level of content exploration and interest (Axelson & Flick, 2010).

Other research has identified good design characteristics for specific types of technologies. Well-designed learner–technology–content interactions accentuate content, prompt learner–content interactions, and focus learners on content during learner–instructor and learner–learner interactions (Murray et al., 2013; Shea, Li, & Pickett, 2006). These interactions prompt thinking, self-regulating, and reflecting and support deep level processing of content (Bernard et al., 2009; Harvey, Coulson, & McMaugh, 2016; Lamb et al., 2018; Liu & Kaye, 2016; Merchant et al., 2014; Mislevy, 2013). They help learners develop confidence in their understanding of content (Duschl, 2003; Munene, Darby, & Doherty, 2015; Sato, 2003), and achieve learning gains (Kluger & DeNisi, 1996). Several studies found that significant relationships developed among learners who reported a sense of connectedness among peers and instructors and cognitive thinking in environments that scaffold their attention to content, self-reflection, and achievement (Liu and Kaye, 2016; Rovai, 2002). Deep learning occurs through interacting with, engaging in, and reflecting on content. These leaning behaviors, as advocated in learning theories, are reflected in good design characteristics. See Table 2.

Research also has identified characteristics of poor designs that tend to distract learners from content learning. Poorly designed resources haphazardly use features that confuse or overload learners, encourage involvement in activities that do not align with content learning outcomes, and distract learners from content, thus do not support deep content learning (Gilbert & Moore, 1998; Oliver, 1999). Mismatching interaction features and learning expectations also impedes content learning (Akdemir & Koszalka, 2008; Kearsley, 1997; Keengwe, Onchwari, & Wachira, 2008; Koszalka & Ganesan, 2004). Thus, developing interactive technology-based learning resources requires design thinking that strategically combines and purposively guides learner–technology interactions and learner–content interactions.

4 Design Principles and Technology Affordances to Support Content Learning

An essential component in designing any interactive technology-based learning resource is drawing learner attention to the content through the technology features (Garrison & Cleveland-Innes, 2005; Rufai, Alebiosu, & Adeakin, 2015; Shea et al., 2006). Reeves et al. (2005) suggested that technology-enhanced resources and environments should be “integrating design principles with technology affordances”

Table 2 Characteristics of poor versus good interactive technology design

Poor design	Good design*
• Lacks pedagogical framework • Inconsistent or haphazard use of features • Too many features or learner decision points • Content not apparent or weakly presented by interactions • Lacks learner choices • Static (one way) content focus • Lacks physical content interaction • Lacks prompting for intellectual, social, and emotional thinking • Lacks prompting for self-regulation • Extraneous design features which interfere with bimodal processing • Formative feedback missing or non-specific • Mismatch between content interaction type and content learning expectations e.g., domain (cognitive, psychomotor, attitude) and level of learning (surface or deep) • Lacks reflection prompts	• Informed by pedagogy[a,b] • Strategic use of features to prompt learner–content interactions[a] • Streamline design to mitigate cognitive load[b] • Content rich interactions[a,b] • Interactions align with and focus on content learning[a,b,c] • Learner-directed choices[b,c] • Dynamic interactions to read or act upon[a] • Prompts physical interaction with content environment[a] • Prompts for intellectual, social, and emotional content engagement[b,c] • Prompts self-regulation[c] • Multiple content representations—text, image, animation, sound[a,b] • Context-sensitive prompts and formative and authentic feedback[a] • Match between content interaction type and content learning expectation e.g., domain and level of learning[b,c] • Prompts reflection[c]

**Notes* Primarily about—[a]Interacting physically; [b]Engaging mentally; [c]Reflecting

(p. 105) to help learners successfully achieve intended learning. Merrill (2002) synthesized a set of design principles suggesting instruction best promotes learning when (i) learners engage in solving real-world problems, (ii) existing knowledge is activated, (iii) new knowledge is demonstrated to the learner, (iv) new knowledge is applied by the learner, and (v) new knowledge is integrated into the learner's world. Others argue that additional parts of this equation are using appropriate pedagogy, prompting self-assessment, and providing feedback, all aligned with content and key learning expectations (Cook-Benjamin, 2018; Lamb et al., 2018; Poll, Widen, & Weller, 2014).

Grabowski and Small (1997) suggested that there are three types of design elements in interactive technology-based (hypertext) applications. These elements include information, instruction, and learning. Information elements organize and provide content, instructional elements provide direction, and learning elements engage participants in active cognitive processing. Technology features may include multiple text (still, animated, captions), visual (live, animated, 3-D), and audio (voice, sounds) elements; hints and tips; noting, capturing, and highlighting functions; assessment tools; on-demand or context-sensitive feedback; social interaction tools; movement options (navigation using menus, joysticks, scrolling, keys, etc.); and other tools that allow learners to create, share, highlight, manipulate, and visualize content. These features range from static viewable resources (e.g., pdf documents) to highly interactive and responsive environments in virtual or real-world contexts. Each feature, however, can be designed to support informational, instructional, and learning needs (See more in Koszalka & Ganesan, 2004).

Matching design principles and technology features in learner–content interaction design can influence learner activity, engagement, satisfaction, and learning outcomes (Cho, 2011; Ekwunife-Orakwue & Teng, 2014) and scaffold learners in choosing strategies that lead to deeper content thinking (Koszalka & Ganesan, 2004). However, it is unclear which features are best at fostering deep learning.

5 Recent Research in Interactive Technologies and Learning

Recent literature analyzed learning outcomes in simulation environments including games and virtual worlds; virtual reality environments; augmented reality environments; and artificial intelligence devices.[1] Patterns emerged across these papers that help unpack the relationships among learning and interactive technologies features. See Table 3.

A meta-analysis of simulations, games, and virtual worlds found that the use of pedagogical models, 3-D environments, and various prompts promoted cognitive gains, higher order thinking, skill development, and affective attributes in learners (Lamb et al., 2018). Features like elaborate feedback, knowledge of correct response, and learner control mechanism stimulated skill and cognitive development and prompted higher levels of motivation and interest likely due to interface, interaction, and feedback design (Lamb et al., 2018; Merchant et al., 2014). Collaborative and competitive activities were perceived as providing an overabundance of interaction that may have slowed or impeded learning.

Virtual reality (VR) and augmented reality (AR) environments use experiential pedagogy to engage learners in intellectual, social, and emotional processes (Oigara, 2018). They are motivational, encourage exploration, prompt interaction through multiple visual and auditory channels, and provide multiple perspectives of content. AR provides context-sensitive overlaid information that enhanced the perceived value of learner–content interaction (van Krevelen & Poelman, 2010). VR and AR provide authentic real-life environments that lull learners into becoming part of a learning environment and give feedback in authentic ways (Oigara, 2018; Rossing, Miller, Cecil, & Stamper, 2012; van Krevelen & Poelman, 2010). Such features scaffold prior knowledge activation and help learners make sense of content (Sousa, 2005).

Artificial Intelligence-based resources use pattern-matching to trigger formative assessment through tutors, robots, or other means. Triggers (text, verbal, visual) help learners monitor their own achievement, identify errors in behaviors or think-

---

[1] Note: This review is not intended to be a full analysis of all recent research. Rather, it is a starting point in unpacking relationships among technologies and learning.

Table 3 Summary of highly interactive technologies with definitions and key design factors

Interactive technology	Definition	Key design factors in learner–content interaction*
Simulations (see Sauve, Renaud, Kaufman, & Marquis, 2007)	Digital environment models reality of a defined system, has fidelity, accuracy, and validity, designed to address learning objectives	• Use of pedagogical models • 3-D environments[a] • Behavior/action prompts[a] • Highly interactive[a] • Inviting interface[a] • Visual and auditory features[a] • Feedback with elaboration[b] • Correct response feedback[b] • Minimal learner assessment[b] • Experiential pedagogy[b]
Educational games (see Sauve et al., 2007)	Environment artificial or fantasy; pre-determined goals; pedagogically based; for one or multiple players	
Virtual worlds (VW) (see Girvan, 2018)	Shared, simulated space inhabited by characters/avatars (learners) who mediate experiences; Avatars share and construct knowledge together	
Virtual reality (VR) (see van Krevelen & Poelman, 2010)	Synthetic, digitally created dynamic view of real world in which learners *interact* with content (higher tech demand vs. VW/VR)	• 3-D environments[a] • Exploratory paths[a] • Intellectual, emotional, and social processes prompts[b] • Multiple perspectives[c] • Authentic—real world[b] • Context-sensitive feedback[b] • Overlay information[b] • Multisensory (visual, sound, tactile)[b] • Experiential pedagogy[b]
Augmented reality (see van Krevelen & Poelman, 2010; Turkan et al., 2017)	Mix of digital VR and real world; Augments overlay real objects; learners prompt augments (higher tech demand than VR)	
Artificial intelligence technologies (see Hoppe, Verdejo, & Kay, 2003)	Digital resources and environments (e.g., intelligent-tutors, -worlds, -communities, robots) built on programs that mimic brain functions	• Auto response/triggers[b] • Shares achievement level[b] • Recognizes and adapts to learner input[b] • Individualized feedback/cues[b]

**Note* All technologies engage learners in problem solving and support cognitive processing; [a]Primarily interaction (physical); [b]Primarily engagement (thinking)

ing, and adapt toward greater content understanding. Pedagogical models, content domain models, and learner behavior data are merged to mimic human-like prompts, questions, alerts, and suggestions that engage learners in thinking while progressing toward deeper content understanding (Chattopodhyay et al., 2018).

5.1 Summary

Interactive technologies have features that are able to support learning when they are designed as problem-centered and activate existing knowledge, demonstrate knowledge, prompt learners to demonstrate knowledge, and engage learners to integrate new knowledge into their own context (Merrill, 2002). Resources that are pedagogically grounded, offer flexibility, provide feedback; prompt self-assessment, and encourage reflective practices can support deep thinking. Several studies confirm specific instances of rich, interactive technology resources and environments that have positively impacted learning.

However, learners' abilities to reach a deeper understanding in these complex technology-based environments is called into question when learners are faced with too many paths or choices and a lack of scaffolding toward content learning (Munene et al., 2015; Sampson, Leonard, Ballenger, & Coleman, 2010). Most of the studies report on surface learning, perception, affect, or behavior patterns. This does not necessarily suggest that interactive technologies do not support deep learning but there is simply a lack of robust research in these technologies specifically that explore deep content thinking. Through the lens of learning theory, relationships between technology features and deep processing of content can be thoroughly investigated.

6 Contributing Theories and Synthesis of Their Tenets

Unpacking relationships among technology features and deep learning processing can be aided by considering theory. Three established educational theories that speak to learner–content interactions and have empirical evidence suggesting deep learning mechanisms [cognitive development] in interactive technology applications include generative learning theory (GLT), cognitive flexibility theory (CFT), and reflection practices (RP). Each provides a theoretical view of deep learning with technologies. We posit that overlapping tenets across these theories provide validity to their principles. Synthesizing these principles with research findings across interactive technology studies mentioned above provides a foundation upon which guidelines can be created to inform the design of interactive technologies that support deep learning. See Table 3.

6.1 Generative Learning Theory (GLT)

Generative Learning Theory (GLT) posits that learning occurs when learners are both physically and cognitively active in organizing and integrating new information into their existing knowledge structures (Grabowski, 2004; Wittrock, 1992). Comprehension and understanding result from generating relationships among existing concepts

Table 4 Four process components of generative learning theory*

	Motivational processes	Learning processes	Knowledge creation processes	Generation processes
Brain function	Arousal and attention	Arousal and attention	Sensory input and integration	Executive planning and organization
Example	Intention (interest)	Attention and focus (sustaining)	Beliefs, pre-conception, conception and meta-cognition	Coding, integration
Learner action	Selectively acknowledge new content based on interest and sense of control	Attention focus on and response to new content that has been acknowledged	Iteratively combine and compare new content to existing knowledge	Create new relationships by integrating, organizing, reconceptualization
Determines	Recognition of stimulus/new content and if generation occurs	Decision to code and integrate new information	Connection quality and type generated on belief, value, and memory	Comprehension level, recall success and retrieval of new content

**Note* Adapted from Wilhelm-Chapin and Koszalka (2016)

and previous experiences with new information and experiences (Wittrock, 1992). Cognitive processing starts with sensory arousal. Learners then actively (physically) and cognitively (mentally) begin to make sense of new information by organizing and integrating it into their existing knowledge schema or, if not perceived as important, dropping it from their thinking. Schema are further developed and modified through four processes—motivational, learning, knowledge creation, and generation. These processes invoke interaction with thinking and in turn lead to generation of new concepts and connections within the learners' schema. See Table 4.

6.2 Cognitive Flexibility Theory (CFT)

Cognitive Flexibility Theory (CFT) suggests that deep learning requires learners to engage with new content from multiple perspectives and in flexible ways of thinking, thus prompting the development of higher order thinking skills (e.g., problem solving), richer cognitive connections, and changes in the learner's affective domain (Spensley & Taylor, 1999; Spiro, Coulson, Feltovich, & Anderson, 1988). Cognitive flexibility is defined as "the ability to spontaneously restructure one's knowledge, in many ways, in adaptive response to radically changing situational demands" (Spiro & Jehng, 1990, p. 165).

CFT maintains that advanced knowledge construction is more than a simple recollection of prepackaged information. Knowledge is formed by actively assembling different knowledge fragments from past experiences and applying them adaptively to solve new problems in a “situation-specific knowledge assembly” process (Spiro et al., 1988, p. 8). As a result, CFT promotes knowledge transfer. In order to be able to use knowledge flexibly, it needs to be learned flexibly. CFT offers several instructional principles that promote such flexibility during learning: ill-structuredness, interconnectedness, irregularity, nonlinearity, flexibility, conceptual variability, multiple representations, early introduction of complexity, multiple perspectives, and criss-crossing of knowledge landscapes (Spiro, Collins, Thota, & Feltovich, 2003; Spiro et al., 1988). These principles can inform the design of complex case studies that entice learners into deep learning by interacting with the content, visualizing and revisiting content, and engaging in analysis, evaluation, reflection, application, and synthesis during learning.

6.3 Reflection Theory (RT)

Reflection theory (RT) suggests that learners engage intellectually and affectively in situations, activities, or resources (Schön, 1983). This reflective engagement leads to deeper understanding, more cognitive connections, appreciations of one’s experiences, self-assessment practices, meaning making, and the ability to transfer newly learned concepts to new situations (Schön, 1983; Wells, 1999; Zimmerman, 1998). Reflection occurs in episodes of self-observation, self-judgment, and self-reaction in which learners evaluate their progress to the goals they have set (Zimmerman, 1998). Forethought is when learners plan for learning and evoke interest, motivation and goal orientation toward learning. The performance phase is where learners employ learning strategies (e.g., time management, volition) to engage in meeting learning goals. Self-reflection is when learners evaluate their performance and achievement of learning goals. Facilitating learners through all three phases assists them in reaching deeper levels of learning (Bannert, 2006; Lin & Lehman, 1999; Moos & Bonde, 2016). See Table 5.

A learner’s ability to self-regulate learning is both cognitive in nature and it is the result of the interaction between personal, environmental, and behavioral influences (Zimmerman, 1998, 2001, 2011). If progress in learning does not match a learning goal, a highly self-regulated learner will use what has been gained from reflection to make changes in learning activities and strategy use (Zimmerman, 1998), thus potentially leading to gains in goal and academic achievement (Schunk & Greene, 2018).

Table 5 Prompts for self-regulated learning leading to self-reflection

Types of prompts	Purpose	Examples: prompts learners to…	Corresponding self-regulation phase
Resources management	Prompts learners to ensure optimal learning conditions	• Gather necessary learning materials • Coordinate groups • Sustain motivation	Forethought
Cognitive	Prompts to support information processing and use of learning strategies	• Stimulate recall • Complete steps in procedure/process • Use cognitive learning strategies	Performance
Metacognitive	Prompts learners to self-monitor and control own learning	• Self-reflect • Use metacognitive learning strategies	Self-reflection

6.4 Summary

Each of the theories described above has empirical evidence suggesting that purposeful learner–content interactions can lead to deeper content learning through prompted content manipulation (acting), thinking, and reflecting (Koszalka, 2016b). Commonalities across these theories suggest leaner-centric design, activating previous knowledge, active participation through physical and cognitive engagement, demonstrating content in multiple formats, encouraging meaning making, and reflecting on content from multiple perspectives are important to deep content learning.

Technology features, when well designed and integrated can support and facilitate all of these learner–content interactions and help learners achieve deeper learning. Thus, these commonalities can help define guidelines for integrating interactive technology features in deep learning resources and environments. See Table 6.

7 Supportive Guidelines for Creating Interactive Technology-Based Learning Resources and Learning Environments

Literature both supports technology uses that enhance learner–content interactions and offers cautions on the overuse (too much), misaligned use (poorly designed), and even lack of use (missed opportunity) of appropriate interactive technology features. Learner–content interactions are important in supporting deep learning and technology-based features can prompt and possibly strengthen content manipulation (interacting), thinking (engagement), and reflecting.

This proposed set of guidelines brings together trends in interactive technology research, theories of deep learning, and design principles in an effort to guide design

Table 6 Commonalities among theories

Theory	Definition	Learning interactions*
Generative learning (Wittrock, 1974)	Learners actively generate new knowledge by mentally forming labeled relationships and connections between new information and prior knowledge/experiences	• Learner centric—toward content understanding • Simultaneous physical and cognitive engagement with content-active • Connect existing knowledge to new information • Encourage generating meaningful connections
Cognitive flexibility (Spiro et al., 1988, 1992)	Learners develop, change, or adapt their content perspective based on engaging in new or complex situations that provide rich information in multiple formats and flexible choices during learning interactions	• Learner centric—toward content understanding • Provide multiple dimensions, perspectives, and rich representations of content • Flexible interactions and interconnections across knowledge/content-active • Prompt thinking of multiple perspectives on, and representations of, content
Reflection (Zimmerman, 2002)	Learners transform experience into deep understanding by thinking continuously about connections they make with content across previous, current, and potential future interactions	• Learner centric—toward content understanding • Prompt self-reflection of observations/experiences to learning goals • Encourage testing concepts in new situations and contexts-active

**Note* All theories suggest deeper levels of cognitive processing based on activating previous knowledge, prompting physical and cognitive interactions, and tapping into self-regulated learning mechanisms (e.g., personal goals, motivation)

of digital learning resources and learning environments. The goal is to prompt learner–content interactions in ways that support deep content learning.

The guidelines are presented in four focus areas; general, incorporation of interactions with content, engagement (thinking) on content, and reflecting about content. Each of the four focus areas has 3–6 specific instructional design guidelines and offers several examples of features or activities that may support deep learning in technology-based resources or environments.

The guidelines are flexible in that they can be used to create or enhance static and dynamic resources. They can also be consulted when creating *new* interactive technology-based learning resources and learning environments and when *transforming* existing digital resources and environments into learning resources and learning environments. See Table 7.

Table 7 Guidelines for learner–content interactions to enhance deep learning

Focus	Guidelines*	Example features or activities
General	• Learner centric content focus[a,b,c] • Define content and learning (cognitive, affective, psychomotor; levels of learning low-to-high)[a,b,c] • Create interest in content[a,b,c]	• Interactive interface and features—show examples, stories, applications • Inviting 2D or 3D interface—content focus • Surprise, motion-elicit attention, action, thinking • Multiple content views
Interact physically with content	• Create purposeful interaction[a] • Provide varied interactions[a,b] • Provide choices on how and when to interact, with whom[a,b] • Encourage content exploration[a,b]	• Prompts explore actions • Various interaction types • Multiple pathways and options • Social networking
Engage in thinking about content	• Prompt summarizing, organizing[a] (low-level thinking) • Prompt synthesizing, predicting[a] (high-level thinking) • Provide multiple representations[b] • Prompt thoughtful practice interactions with content[a,b,c] • Prompt thinking about the what's and why's of physical interactions—what am I doing, what am I learning, what can I do with this knowledge, and why?[a,b,c]	• Multisensory content—image, sound, tactile • Context-sensitive feedback, questioning • Prompts to hypothesize, test, check—social • Periodic hints, summaries • Variety of summaries—graphics, charts, audio • Multiple assessment types at multiple levels • Auto responses, triggers to summarize content
Reflect on content learning	• Prompt self-assessment[a,b,c] • Prompt reflection on how content can be used now and in the future, in learner's world[b,c] • Prompt reflection on understanding[c] • Prompt goal and expectation setting[c] • Prompt reflection on feelings[c] • Prompt reflection on meeting goals[c]	• Goal setting prompts • Intermittent questions on content applications, learning, feelings • Achievement level self-check, progress feedback • Individualized and context-sensitive feedback, questioning

**Note* [a]Generative learning, [b]Cognitive flexibility, [c]Reflection

8 Transforming Static and Dynamic Resources into Learning Resources

These guidelines can be used to transform resources into learning resources through purposeful learner–content interactions. Ideally, these guidelines are used in the initial design and development phases when creating new experiences. Incorporating context-sensitive prompts, access to multiple views of content (e.g., text, graphics, motion, still), providing thinking prompts (e.g., what happened? Why is this important? What is next?), and offering help can instigate physical activity, thinking, and reflection.

These types of features can assure that learner–content interactions standout in the learning resource and are well and consistently designed from the start. It is more efficient to design learner–content interactions early in the development process than having to make major adjustments later.

The initial steps of any complex development process are to define what the resources or environment will "do" and what the users will "accomplish." The guidelines lend themselves to thinking about how to use available technology features to prompt deep learning (accomplishment of learner). Revisiting them during development reviews can help maintain consistency in learner–content interactions that will support deep learning.

For example, when creating a simulation or augmented reality world on identifying business problems or working with chemical reactions identifying features in the technology platform (e.g., content overlays, feedback, prompts) and how they will be used to support interacting, thinking, and reflecting will help frame the learner–content interactions. Establishing these decisions early in the design process helps avoid major revisions later in the development process. They also assure that the content interaction, thinking, and reflecting focus is maintained in the environment, throughout the development process and when the resources are being used by learners. Establishing guidelines based on theory and supported by rigorous research studies can foster creation of educational technologies that promote deep learning.

However, sometimes existing digital resources and environments are used that are not editable. This does not discount the possibility of transforming them into learning resources aimed at prompting deep learning. Existing digital resources, whether static (e.g., pdf) or dynamic (e.g., interactive simulation), can be transformed into content learning resources with the addition of supporting instructional materials that are used side-by-side with existing resource to prompt learners interacting, thinking, and reflecting that is not prompted in the existing resource.

For example, learners may have access to a digital information sources like pdf articles or web-based simulations to learn content. These content sources already exist. Reviewing these types of resources may lead to deep learning; however, their use often results in surface level learning (Laird et al., 2005). Transforming these types of resources into learning resources may be accomplished by adding enhanced learner–content interactions that facilitate focused learner–content interactions using the features of the original digital resource and prompting activities.

Two examples are provided to demonstrate how existing resources and the development of new learning resources might incorporate the guidelines of good design for instructional technology and the proposed guidelines for enhancing learner–content interactions. The static and dynamic resource transformations also highlight links to generative learning theory (GLT), cognitive-flexibility theory (CFT), and reflection theories (RT) which have been shown to enhance deep learning.

8.1 Transforming Static Resources

Consider learners provided with a pdf article that describes the anatomy of a plant cell. They are prompted to read the article and be able to describe all the key parts of a cell in a test. With no further prompting learners may take a variety of approaches to learning that may include printing and highlighting the file, taking notes, creating flash cards, or some other memorization type activity. These interactions are helpful in achieving surface level learning and likely short-term memory.

Considering the guidelines above, prompting learners to use pdf software features to highlight cell organelle names in blue (on the pdf), underline organelle descriptions in blue, underline description of organelle function in black, highlight functions of organelles that relate to other organelles by drawing highlighted lines between the organelles in yellow, etc. These interactions require learners to manipulate and organize content, think about what the text is saying, and make decisions about what to highlight and underline (GLT/CF). These are deep thinking activities. Learners could be further prompted to use text editing software (e.g., word) to create a table demonstrating their knowledge of the content and classifying each organelle according to its main function (GLT). They may be prompted in another way, perhaps to use concept-mapping software to draw a map of their understanding of the connections among organelles (GLT), incorporate graphics of the organelle (CF), and reflect and write about on how well they understand the anatomy of the plant cell (RT). These types of learner–content interactions help learners generate new concepts and relationships in their existing schema, adding to their depth of knowledge.

Another option might be to prompt the learner to create a short instructional presentation on the anatomy of a plant cell. Provided guidelines may request that graphics, animations, narration, and progressive disclosure be added to the presentation and that each slide include some type of probing question about the slide content to prompt thinking in the audience. Thus, learners creating the presentation are engaged in higher level thinking, applying what they learned, analyzing importance of information, and creating a new and multiple representations of the content (GLT, CF, RT) (Anderson et al., 2001).

The goal is not to recreate the pdf content to make it more interactive, rather the goal is to prompt learner–content interaction, thinking, and reflecting. The learner makes the choice of how to interact and study with the pdf file. The suggested uses of technology features beyond reading scaffolds learners to move from surface level strategies to deep level thinking.

8.2 Transforming Dynamic Resources

The same type of transformation can occur with existing dynamic digital resources. For example, consider an interactive simulation about cells, where the learner can click on the cell organelles and get information on each, and manipulate a 3-D view of the cell anatomy. Explanations are offered about how the organelles function and the graphics show what they look like within the cell. This is similar to an augmented reality environment in that the text or audio features overlay the view of the actual cells and are revealed when activated by the learner. Since this simulation is already created, there may be no way to add additional prompting inside the simulation to support learning for specific purposes. However, to support deeper learning an additional learning resource may be created to prompt deeper learning rather than just interacting (playing) with the simulation.

Similar to those described above, learning resources can be created to prompt learners to play with the simulation and simultaneously create a table or a concept map or a presentation of the organelles, their characteristics, and their functions (GLT/CF). Reflection questions can be added to prompt learners to reflect on how they understand the content, how helpful it was for them to view the cell from multiple perspectives, and how they might use this information in the future (RT). Supporting learner–content interactions based on the proposed guidelines may enhance deeper learning.

The challenge with existing digital resources and environments is to create supporting learning activities and resources that help learners focus on content in ways that will activate deeper thinking. Simply suggesting ways to interact, think, and reflect while using provided static or dynamic resources may move learners from choosing surface level approaches to choosing deep learning approaches. Research to better understand the effect and extent to which learning resources support deep learning processing is ongoing.

8.3 Summary

Although the proposed design guidelines presented here are based in theories that have decades of supporting research behind them, much of the cited research was focused on a specific technology (e.g., simulation, interactive video, concept mapping), content domain (e.g., mathematics, reading), age level (e.g., young students, adults), and generally through multiple short-term studies of a single technology to test theoretical ideas. Additional research is needed to validate the proposed design guidelines presented here for using specified types of technology features across different technologies with different levels of audiences, and a variety of content domains to promote deeper learning. It is also be important to identify and further understand the types of learner behaviors exhibited while interacting with different types of technologies, specifically looking for those behaviors that infer deep content learning, ultimately validating the assumption that generative learning, cognitive flexibility, and reflection theories can indeed guide the use of technology features to enhance deep learning. There is a need to conduct longitudinal research across content domains, technologies, and static and dynamic technology resources to extract common design principles that may provide valid ideas to enhance technology feature use across different technologies (e.g., simulations, VR). It will also be important to look at the long term affects different technology features may have on promoting or inhibiting deep learning. It will also be important to look at when highly immersive (more expense and consuming) technologies are better or worse at supporting content learning than lower level technology resources (less expense and consuming). These types of research agendas may help unpack the complexities of learning through technology interactions (physical manipulation) and learning based on content engagement (cognitive manipulation).

9 Summary

Interactive technologies are inundating learning activities. Multiple features offered by technologies give learners options to interact with, engage in, and reflect on learning content. New technologies are offering more exciting and contextualized resources and environments than ever before. The questions explored in this chapter were about how to design effective learner–content interactions by assuring the resources and environments encourage interaction *WITH* engagement in thinking and reflection, by transforming resources and environments into learning resources and learning environments. There is no guarantee that highly immersive, or low technology-enhanced, experiences are going to be better or worse at supporting deep learning. Theory and research can inform characteristics of technology uses that are predictive of deep learning. By combining what is theorized about the mechanisms of deep learning, design principles, and appropriate technology features, a set of guidelines has been proposed to support the design of learner–content interactions. Further research is necessary to validate these guidelines and their application to a variety of emerging interactive technologies and content applications.

The goal is to take a strategic perspective in incorporating what is known about learning when creating or transforming resources to support deep learning. We likely have not yet fully explored what technologies can do to attract and lull learners into deep thinking and how to avoid designs and interactions that distract and inhibit learning. Learners are complex beings who must choose to think during the learning process. Helping learners make this choice is a complex idea; however, the process can be informed by research.

Regardless of the technology of choice, one of the most critical interactions in the learning process is the learner–content connection. Focusing on that interaction goes far in designing purposeful instruction.

References

Akdemir, O., & Koszalka, T. (2008). Investigating the relationships among instructional strategies and learning styles in online environments. *Computers & Education, 50*(4), 1451–1461.

Alimisis, D. (2016). Robotics in education & education in robotics: Shifting focus from technology to pedagogy. In *Paper published in 3rd International Conference on Robotics in Education*, Prague (pp. 7–14).

Anderson, L. W., Krathwohl, D. R., Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., …, & Wittrock, M. C. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives.* New York: Pearson, Allyn & Bacon.

Anderson, R. C., & Pearson, P. D. (1984). A schema-theoretic view of basic processes in reading comprehension. In P. D. Pearson (Ed.), *Handbook of reading research* (pp. 255–311). Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

Anderson, T. (2003). Getting the mix right again: An updated and theoretical rationale for interaction. *International Review of Research in Open and Distance Learning, 4*(2), 9–14.

Axelson, R. D., & Flick, A. (2010). Defining student engagement. *The Magazine of Higher Learning, 43*(1), 38–43. https://doi.org/10.1080/00091383.2011.533096.

Bannert, M. (2006). Effects of reflection prompts when learning with hypermedia. *Journal of Educational Computing Research, 35*(4), 359–375. https://doi.org/10.2190/94V6-R58H-3367-G388.

Bernard, R. M., Abrami, P. C., Borokhovski, E., Wade, C. A., Tamim, R. M., Surkes, M. A., & Bethel, E. C. (2009). A meta-analysis of three types of interaction treatments in distance education, *Review of Educational Research, 79*(3), 1243–1289.

Biggs, J. B. (1987). *Student approaches to learning and studying*. Melbourne: Australian Council for Educational Research.

Biggs, J. B. (1989). Approaches to the enhancement of tertiary teaching. *Higher Education Research and Development, 8,* 7–25.

Biggs, J. B. (2003). *Teaching for quality learning at university: What the student does*. Buckingham: Open University Press.

Bloom, B. S. (1956). *Taxonomy of educational objectives. Vol. 1: Cognitive domain* (pp. 20–24). New York: McKay.

Bowden, J., & Marton, F. (1998). *The university of learning: Beyond quality and competence*. London: Kogan Page.

Chattopadhyay, S., Gangadhar, R. B., Shankar, S., & Kasinathan, K. (2018). Applications of artificial intelligence in assessment for learning in schools. In J. Keengwe (Ed.), *Handbook of research on digital content, mobile learning, and technology integration models in teacher education* (pp. 185–206). Hershey, PA: IDE Global.

Cho, T. (2011). The impact of types of interaction on student satisfaction in online courses. *International Journal on E-Learning, 10*(2), 109–125.

Cook-Benjamin, L. (2018). Best practices to support online student engagement. In J. Keengwe (Ed.), *Handbook of research on digital content, mobile learning, and technology integration models in teacher education* (pp. 287–299). Hershey, PA: IDE Global.

Cummings, C., Shelton, K., Mason, D., & Baur, K. (2015). Active learning strategies for online and blended learning environments. In J. Keengwe & J. J. Agamba (Eds.), *Models for improving and optimizing blended learning in higher education* (pp. 58–82). Hershey, PA: IGI Global.

Curton, B., & Moreno, V. (2016). Robotics in education. *Journal of Intelligent Robot Systems, 81,* 3–4.

Dave, R. H. (1971). *Developing and writing behavioral objectives*. Tucson, AZ: Educational Innovators Press.

Dennis, J. P., & Vander Wal, J. S. (2010). The cognitive flexibility inventory: Instrument development and estimates of reliability and validity. *Cognitive Therapy and Research, 34*(3), 241–253.

Dick, W., & Carey, L. (1978). *The systematic design of instruction*. Glenview, Illinois: Scott, Foresman and Company.

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

Duschl, R. (2003). Assessment of inquiry. In M. Atkin & J. E. Coffey (Eds.), *Everyday assessment in the science classroom* (pp. 41–59). Arlington, VA: NSTA Press.

Ekwunife-Orakwue, K., & Teng, T. (2014). The impact of transactional distance dialogic interactions on student learning outcomes in online and blended environments. *Computers & Education, 78,* 414–427. https://doi.org/10.1016/j.compedu.2014.06.011.

Elder, L., & Paul, R. (2009). *Critical thinking: Concepts and tools* (6th ed.). Foundation for Critical Thinking Press.

Entwistle, N. J. (1981). *Styles of learning and teaching: An integrated outline of educational psychology students, teachers, and lectures*. New York: Wiley.

Gagné, R. M. (1985). *The conditions of learning and theory of instruction*. New York: Holt, Rinehart and Winston.

Gagné, R. M., & Briggs, L. (1979). *Principles of instructional design*. Holt, Rinehart and Winston.

Gagné, R. M., & Briggs, L. J. (1996). *Principles of instructional design*. New York: Holt, Rinehart, and Winston.

Garrison, D. R., Anderson, T., & Archer, W. (2001). Critical thinking, cognitive presence, and computer conferencing in distance education. *The American Journal of Distance Education, 15*(1), 7–23.

Garrison, D. R., & Cleveland-Innes, M. (2005). Facilitating cognitive presence in online learning: Interaction is not enough. *American Journal of Distance Education, 19*(3), 133–148. https://doi.org/10.1207/s15389286ajde1903_2.

Gilbert, L., & Moore, D. (1998). Building interactivity in Web courses: Tools for social and instructional interaction. *Educational Technology, 38,* 29–35.

Girvan, C. (2018). What is a virtual world? Definition and classification. *Education Technology Research and Development,* 1–14. https://doi.org/10.1007/s11423-018-9577-y.

Grabowski, B. L. (2004). Generative learning contributions to the design of instruction and learning. In D. H. Jonassen & Association for Educational Communications and Technology (Eds.), *Handbook of research on educational communications and technology* (2nd ed., pp. 719–743). Mahwah, NJ: Lawrence Erlbaum.

Grabowski, B., & Small, R. (1997). Information, instruction, and learning: A hypermedia perspective. *Performance and Improvement Quarterly, 10,* 156–166.

Harvey, M., Coulson, D., & McMaugh, A. (2016). Toward a theory of the ecology of reflection: Reflective practice for experiential learning in higher education. *Journal of University Teaching and Learning Practice, 13*(2), 1–20.

Hoppe, U., Verdejo, M. F., & Kay, J. (2003). *Artificial intelligence in education: Shaping the future of learning through intelligent technologies*. Amsterdam, Netherlands: IOS Press.

Jonassen, D., Campbell, J., & Davidson, M. (1994). Learning with media: Restructuring the debate. *Educational Technology Research and Development*, *42*(2), 31–39. Retrieved from http://www.jstor.org/stable/30218685.

Kearsley, G. (1997). A guide to online education. Retrieved from http://gwis.circ.gwu.edu/~etl/online.html.

Keengwe, J., Onchwari, G., & Wachira, P. (2008). Computer technology integration and student learning: Barriers and promise. *Journal of Science Education, 17,* 560–565. https://doi.org/10.1007/s10956-008-9123-5.

Kluger, A. N., & DeNisi, A. (1996). The effects of feedback interventions on performance: A historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychological Bulletin, 119*(2), 254–284. https://doi.org/10.1037/0033-2909.119.2.254.

Koehler, M., & Mishra, P. (2009). What is technological pedagogical content knowledge (TPACK)? *Contemporary Issues in Technology and Teacher Education, 9*(1), 60–70. Waynesville, NC, USA: Society for Information Technology & Teacher Education. Retrieved from https://www.learntechlib.org/primary/p/29544/.

Kolb, A., & Kolb, D. (2012). Experiential learning theory. In N. Seel (Ed.), *Encyclopedia of the sciences of learning* (pp. 1215–1219). U.S.: Springer. https://doi.org/10.1007/978-1-4419-1428-6_227.

Koszalka, T. A. (2016a). *What is RIDLR [Research in designing learning resources] all about?* [Narrated video]. Retrieved from http://ridlr.syr.edu/about/.

Koszalka, T. A. (2016b). *Reflection and its application to learning resources.* [Concept paper]. Retrieved from http://ridlr.syr.edu/publications/.

Koszalka, T. A., & Ganesan, R. (2004). Designing online courses: A taxonomy to guide strategic uses of features available in distance education course management systems (CMS). *Distance Education, 25*(2), 243–256.

Koszalka, T., & Ntloedibe-Kuswani, G. S. (2010). Literature on the safe and disruptive learning potential of mobile-technologies. *Distance Education, 31*(2), 139–150.

Krathwohl, D. R., Bloom, B. S., & Masia, B. B. (1964). *Taxonomy of educational objectives, handbook II: Affective domain*. New York: David McKay Company Inc.

Laird, T. F., Shoup, R., & Kuh, G. (2005). *Measuring deep approaches to learning using the national survey of student engagement*. Paper Presented at the Annual Meeting of the Association for Institutional Research, Chicago, Il.

Lamb, R. L., Annetta, L., Firestone, J., & Etopip, E. (2018). A meta-analysis with examinations of moderators of student cognition, affect, and learning outcomes while using serious educational games, serious games, and simulations. *Computers in Human Behavior, 80,* 158–167.

Li, Y., & Wang, L. (2018). Using iPad-based mobile learning to teach creative engineering within a problem-based learning pedagogy. *Educational and Information Technologies, 23,* 555–568.

Lin, X., & Lehman, J. D. (1999). Supporting learning of variable control in a computer-based biology environment: Effects of prompting college students to reflect on their own thinking. *Journal of Research in Science Teaching, 36*(7), 837–858.

Littlejohn, A. (2003). *Using online resources: A sustainable approach to e-learning*. Great Britain: Kogan Page Limited.

Liu, J. C., & Kaye, E. R. (2016). Preparing online learning readiness with learner-content interactions: Design for scaffolding self-regulated learning. In L. Kyeo-Blankson, J. Blankson, E. Ntuli, & C. Agyeman (Eds.), *Handbook of research on strategic management or interaction, presence, and participation in online courses* (pp. 216–244). Hershey, PA: Information Science Reference IDE Global.

Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students learning outcomes in K-12 and higher education: A meta-analysis. *Computers & Education, 70,* 29–40. https://doi.org/10.1016/j.compedu.2013.07.033.

Merriam, S. B., Caffarella, R. S., & Baumgartner, L. (2007). *Learning in adulthood: A comprehensive guide* (3rd ed.). San Francisco, CA: Jossey-Bass.

Merrill, D. M. (2002). First principles of instruction. *Educational Technology Research and Development, 50*(3), 43–59.

Mislevy, R. J. (2013). Evidence-centered de-sign for simulation-based assessment [Supplemental Material]. *Military Medicine*, *178*(10), 107–114. https://doi.org/10.7205/milmed-d-13-00213PMID:24084311.

Moos, D. C., & Bonde, C. (2016). Flipping the classroom: Embedding self-regulated learning prompts in videos. *Technology, Knowledge, and Learning, 21*(2), 225–242. https://doi.org/10.1007/s10758-015-9269-1.

Munene, I. I., Darby, F., & Doherty, J. (2015). Blended for student engagement and retention: The case of cinema and visual culture and healthy lifestyle studies. In J. Keengwe & J. J. Agamba (Eds.), *Models for improving and optimizing blended learning in higher education* (pp. 129–146). Hershey, PA: IGI Global.

Murray, M., Pérez, J., Geist, D., & Hedrick, A. (2013). Student interaction with content in on-line and hybrid courses: Leading horses to the proverbial water. *Informing Science, 16,* 99–115.

Oigara, J. N. (2018). Integrating virtual reality tools into classroom instruction. In J. Keengwe (Ed.), *Handbook of research on mobile technology, constructivism, and meaningful learning* (pp. 147–159). Hershey, PA: IGI Global.

Oliver, R. (1999). Exploring strategies for online teaching and learning. *Distance Education, 20,* 240–250.

Ormrod, J. E. (2016). *Human learning* (7th ed.). Upper Saddle River, NJ: Pearson Education.

Passey, D., & Hobrecht, P. (2001). Online resources and effective teaching and learning. *Education, 29*(1), 3–13. https://doi.org/10.1080/03004270185200021.

Paul, R., & Elder, L. (2007). *A guide for educators to critical thinking competency standards*. Foundation for Critical Thinking Press.

Poll, K., Widen, J., & Weller, S. (2014). Six instructional best practices for online engagement and retention. *Journal of Online Doctoral Education, 1*(1), 1–17.

Prosser, M., & Millar, R. (1989). The "how" and "why" of learning physics. *European Journal of Psychology of Education, 4,* 513–528.

Ramsden, P. (2003). *Learning to teach in higher education*. London: Routledge Falmer.

Reeves, T. C., Herrington, J., & Oliver, R. (2005). Design research: A socially responsive approach to instructional technology research in higher education. *Journal of Computing in Higher Education, 16*(2), 96–115. https://doi.org/10.1007/BF02961476.

Reiser, R. A. (2001a). A history of instructional design and technology: Part I: A history of instructional media, *Educational Technology Research and Development, 49*(53). https://doi.org/10.1007/BF02504506.

Reiser, R. A. (2001b). A history of instructional design and technology: Part II: A history of instructional Design, *Educational Technology Research and Development, 49*(57). https://doi.org/10.1007/BF02504928.

Rossing, J. P., Miller, W. M., Cecil, A. K., & Stamper, S. E. (2012). iLearning: The future of higher education? Student perceptions on learning with mobile tablets. *Journal of the Scholarship of Teaching and Learning, 12*(2), 1–26.

Rovai, A. P. (2002). Sense of community, perceived cognitive learning, and persistence in asynchronous learning networks. *The Internet and Higher Education, 5*(4), 319–332.

Rufai, M. M., Alebiosu, S. O., & Adeakin, O. A. S. (2015). A conceptual model for virtual classroom management. *International Journal of Computer Science, Engineering and Information Technology, 5*(1), 27–32.

Rumelhart, D. E. (1980). Schemata: The building blocks of cognition. In R. J. Spiro, B. Bruce, & W. F. Brewer (Eds.), *Theoretical issues in reading and comprehension* (pp. 33–58). Hillsdale, NJ: Erlbaum.

Rumelhart, D. E., & Norman, D. A. (1978). Accretion, tuning, and restructuring: Three modes of learning. In J. W. Cotton & R. L. Klatzky (Eds.), *Semantic factors in cognition* (pp. 37–53). Hillsdale, NJ: Lawrence Erlbaum Associates.

Rumelhart, D. E., & Norman, D. A. (1981). Analogical processes in learning. In J. R. Anderson (Ed.), *Cognitive skills and their acquisition* (pp. 335–359). Hillsdale, NJ: Lawrence Erlbaum Associates.

Sampson, P., Leonard, J., Ballenger, J., & Coleman, J. (2010). Student satisfaction of online courses for educational leadership. *Online Journal of Distance Learning Administration*, *13*(3). Retrieved from http://www.westga.edu/~distance/ojdla/Fall133/sampson_ballenger133.html.

Sato, M. (2003). Working with teachers in assessment-related professional development. In J. M. Atkin & J. E. Coffey (Eds.), *Everyday assessment in the science classroom*. Arlington, VA: NSTA Press.

Sauve, L., Renaud, L., Kaufman, D., & Marquis, S. (2007). Distinguishing between games and simulations: A systematic review. *Journal of Educational Technology & Society, 10*(3), 247–256.

Schön, D. A. (1983). *The reflective practitioner*. USA: Basic Books.

Schunk, D. H., & Greene, J. A. (2018). History, contemporary, and future perspectives on self-regulated learning and performance. In D. H. Schunk & J. A. Greene (Eds.), *Handbook of self-regulated learning and performance* (2nd ed., pp. 1–15). New York: Routledge.

Shea, P., Li, C. S., & Pickett, A. (2006). A study of teaching presence and student sense of learning community in fully online and web-enhanced college courses. *The Internet and Higher Education, 9*(3), 175–190. https://doi.org/10.1016/j.iheduc.2006.06.005.

Sousa, D. (2005). *How the brain learns to read*. Thousand Oaks, CA: Corwin Press.

Spensley, F., & Taylor, J. (1999). The development of cognitive flexibility: Evidence from children's drawings. *Human Development, 42*(6), 300–324.

Spiro, R. J., Collins, B. P., Thota, J. J., & Feltovich, P. J. (2003). Cognitive flexibility theory: Hypermedia for complex learning, adaptive knowledge application, and experience acceleration. *Educational Technology, 43*(5), 5–10.

Spiro, R. J., Coulson, R. L., Feltovich, P. J., & Anderson, D. K. (1988). Cognitive flexibility theory: Advanced knowledge acquisition in ill-structured domains. *Technical Report No. 441*.

Spiro, R. J., Feltovich, P. J., Jacobson, M. J., & Coulson, R. L. (1992). Cognitive flexibility, constructivism and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains. In T. Duffy & D. Jonassen (Eds.), *Constructivism and the technology of instruction*. Hillsdale, NJ: Erlbaum.

Spiro, R. J., & Jehng, J.-C. (1990). Cognitive flexibility and hypertext: Theory and technology for the nonlinear and multidimensional traversal of complex subject matter. In D. Nix & R. Spiro (Eds.), *Cognition, education, and multimedia: Exploring ideas in high technology* (pp. 163–205). Hillsdale, NJ: Lawrence Erlbaum Associates.

Tagg, J. (2003). *The learning paradigm college*. Boston, MA: Anker.

Turkan, Y., Radkowski, R., Karabulut-llgu, A., Behzadan, A. H., & Chen, A. (2017). Mobile augmented reality for teaching structural analysis. *Advanced Engineering Infomatics, 34,* 90–100.

van Krevelen, D. W. F., & Poelman, R. (2010). A survey of augment reality technologies, application and limitations. *International Journal of Virtual Reality, 9*(2), 1–10.

Van Rossum, E. J., & Schenk, S. M. (1984). The relationship between learning conception, study strategy and learning outcome. *British Journal of Educational Psychology, 54,* 73–83.

Vos, N., van der Meijden, H., & Denessen, E. (2011). Effects of constructing versus playing an educational game on student motivation and deep learning strategy use. *Computer & Education, 56*(1), 127–137. https://doi.org/10.1016/j.compedu.2010.08.013.

Wells, G. (1999). *Dialogic inquiry*. Cambridge: Cambridge University Press.

Wilhelm-Chapin, M. K., & Koszalka, T. A. (2016). *Generative learning theory and its application to learning resources* [concept paper]. Retrieved from http://ridlr.syr.edu/publications/.

Wittrock, M. C. (1974). Learning as a generative process. *Educational Psychologist, 11,* 87–95.

Wittrock, M. C. (1992). Generative learning processes of the brain. *Educational Psychologist, 27*(4), 531–541. http://dx.doi.org/10.1207/s15326985ep2704_8.

Zimmerman, B. J. (1998). Developing self-fulfilling cycles of academic regulation: An analysis of exemplary instructional models. In D. H. Schunk & B. J. Zimmerman (Eds.), *Self-regulated learning: From teaching to self-reflective practice* (pp. 1–19). New York, NY, US: Guilford Publications.

Zimmerman, B. J. (2001). Theories of self-regulated learning and academic achievement: An overview and analysis. In B. J. Zimmerman & D. H. Schunk (Eds.), *Self-regulated learning and academic achievement: Theoretical perspectives* (pp. 1–37). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory into Practice, 41*(2), 64–70. https://doi.org/10.1207/s15430421tip4102_2.

Zimmerman, B. J. (2011). Motivational sources and outcomes of self-regulated learning and performance. In B. J. Zimmerman & D. H. Schunk (Eds.), *Handbook of self-regulation of learning and performance*. New York: Routledge.

Chapter 3
Creating Dialectics to Learn: Infrastructures, Practices, and Challenges

John M. Carroll, Na Sun and Jordan Beck

1 Introduction

Dialectic refers to methods of discussion and analysis in which a proposition and its antithesis are considered together in order to synthesize a resolution, or at least a more comprehensive solution. Dialectic is an indispensable tool in philosophy, from the Greeks through to Marx and Hegel. It is also the foundation for pragmatic educational concepts like critical thinking and problem-based learning (Dewey, 1933; Pavlidis, 2010).

Dialectical constructivist learning activities articulate multiple perspectives and then comparatively debate, deconstruct, and analyze their strengths and weaknesses to synthesize new perspectives (Cooner, 2005; Moshman, 1982; O'Donnell, 2012; see also Jonassen & Kim, 2010). It can be contrasted with near-neighbor constructivist pedagogies such as problem-based learning (Hmelo-Silver, 2004; Carroll & Rosson, 2005) and endogenous constructivism (O'Donnell, 2012).

Problem-based learning is an exogenous constructivism in which learners address authentic problems with realistic methods, reconstructing relationships and practices

---

J. M. Carroll (✉)
College of Information Sciences and Technology, Pennsylvania State University, 332 Info Science and Tech, E319 Westgate Building, University Park, PA 16802, USA
e-mail: jcarroll@ist.psu.edu
URL: http://jcarroll.ist.psu.edu

N. Sun
College of Information Sciences and Technology, Pennsylvania State University, 332 Info Science and Tech, E363 Westgate Building, University Park, PA 16802, USA
e-mail: nzs162@psu.edu
URL: http://personal.psu.edu/nzs162/

J. Beck
College of Information Sciences and Technology, Pennsylvania State University, E374 Westgate Building, University Park, PA 16802, USA
e-mail: jeb560@psu.edu

P. Díaz et al. (eds.), *Learning in a Digital World*, Smart Computing and Intelligence, https://doi.org/10.1007/978-981-13-8265-9_3

of the real world in order to understand its concepts and techniques. Endogenous constructivism (O'Donnell, 2012) is an approach in which students integrate and coordinate their knowledge and experience to create a reflective abstraction. A contemporary example is the collaborative development of high-quality question/answer pairs, as implemented through Piazza (piazza.com; e.g., Vivian, Falkner, & Falkner, 2013).

Dialectical constructivism can be contrasted with other constructivist pedagogies in three respects. First, dialectical constructivism specifically emphasizes argumentation and debate among learners. The student's role is to challenge and modify perspectives, not just to learn them or even just to put them into practice (Herreid, 2004). Sanders, Wiseman, and Gass (1994) showed that college students could be systematically instructed to effectively and non-aggressively deconstruct arguments. In our work, we aimed to investigate whether argumentation and debate could be more pervasively appropriated by students as a general classroom practice and extended so that students compare and contrast arguments and perspectives, and not merely assess their individual validity.

Second, relative to other constructivist pedagogies, dialectical constructivism emphasizes the synthesis of new perspectives. Exogenous constructivism emphasizes adoption and enactment of pre-existing, authentic knowledge and practices. Endogenous constructivism emphasizes the coordination and reorganization of pre-existing knowledge and practices (Moshman, 1982; Land, 2000). Dialectical constructivism also depends on bottom-up anchoring and appropriation, but it further engages conflicts in understanding (Piaget & Inhelder, 1969) and cultural-material values (Vygotsky, 1978) to evoke sense making. As Kuhn (1999) put it, "The developmental goal is to put people in metacognitive and metastrategic control of their own knowing." We wanted to investigate how students could deliberate, analyze, and resolve conflicting perspectives and in doing so, come to understand issues more broadly.

Finally, relative to other constructivist pedagogies, dialectical constructivism emphasizes that knowledge is problematic and contingent, that people are responsible for constructing it and critically assessing it, and that the challenge of problematic and contingent knowledge is unending (Dalgarno, 2001; Land & Hannafin, 1996). Articulating questions, recognizing information needs, positioning relevant information resources, and synchronizing theories and evidence builds critical thinking skills (Land, 2000; Land & Hannafin, 1997; Rakes, 1996). By contrast, in problem-based learning the focus is on learning and enacting authentic concepts and practices but not necessarily on reflecting upon the limitations and ephemeral validity of the authentic materials.

In this chapter, we address the challenge of helping students understand, learn and adopt critical thinking practices in constructing their own knowledge by implementing and investigating dialectical constructivist learning. We operationalize dialectical constructivism as a knowledge-building activity in which students identify pro and con positions for theories, methods, and arguments in learning materials such as textbooks, and lectures. Students distinguish and articulate pro and con positions, provide empirical or logical backing and subsequently reflect on the pro/con debate in order to synthesize conclusions. This is intended to help students appreciate, understand, and learn how to create a comprehensive analysis of a complex issue as opposed to selecting and defending a position.

2 Case Studies in Dialectical Learning Environments

We introduce three case studies in dialectical learning environments that vary from residential classes of an iSchool institute to moderated online debating activities in the wild.

2.1 Undergraduate Honors Course: Reappropriating Piazza for Argumentation

Our first study was carried out in the context of a university seminar. We appropriated the free Internet platform Piazza (piazza.com), which was developed to support question-answer development. The pedagogical vision of Piazza is that posing good questions is a key learning objective. Good questions are better at evoking good answers. In Piazza, students can successively edit questions and answers, other students can further revise and refine, and also discuss questions and answers developed by others.

We studied a first-year *honors* seminar, meaning that it was oriented toward helping students develop skill in critical thinking. We reappropriated Piazza by having students use its question/answer support to construct pro/con debates about argumentative books they had read: Piazza provides wiki-style collaborative editing support for a Question text pane, and one team students worked to enumerate the points of an author's argument (the pro position). Directly below the Question pane, is Piazza's Answer pane; another team of students presented a con argument, rebutting, questioning or qualifying the author's pro argument point-by-point. At the bottom of the Piazza user interface, Piazza has a discussion forum; students could use it to suggest follow-up discussions about points argued in the pro and con debate.

2.1.1 Participants

The participants were the 15 first-year university students enrolled in "Information, People, and Technology". The class is a general education course for honors students at Pennsylvania State University, and also serves as the entry-point course for an interdisciplinary undergraduate major in Information Sciences and Technology (IST). Five of the students were indeed starting the IST major. Five others were majoring in engineering; four were majoring in liberal arts; one was majoring in communication studies. Four of the students in the class were female (one from each of the majors mentioned above). The students were organized into four teams, before meeting the instructor in the first class, to maximize diversity with respect to gender and major.

2.1.2 Research Design

A key requirement for honors courses in this university is to strongly emphasize critical thinking. During the first class meeting, the instructor demonstrated Piazza and presented a pre-built example of how Piazza could be reappropriated to present a dialectical analysis of issues regarding the US Prism program based on Cho (2013). The concepts and utility of critical thinking, in general, and of pro–con dialectics specifically were stressed.

The major dialectical constructivist activities for the course were analyses of four argumentative books on information technology and society. Each of the books addresses current and controversial issues in computing and information technology as evidenced-based debate, and with a clear point of view. The books present specific and provocative theses about technology, information and people without attempting to present a balanced case. For example, Carr (2015) argues that the use of the Internet is undermining human brains and intellectual abilities, and indeed, that these negative effects are clearest among young people. We anticipated that these books would be compelling, and hypothesized that students would learn more from them by explicitly articulating the implicit dialectic, that is, by concretely enumerating the author's arguments and *constructing counterarguments*.

We instructed students to use a variant of Toulmin (1964) rhetorical categories to construct their arguments: claims, evidence, warrant, backing, rebuttal, qualifier, synthesis, and Socratic questions (a category we added). Each point the students made in their pro or con pane was annotated with a Toulmin "tag" (e.g., [Claim]), indicating which rhetorical category the point belonged to.

2.1.3 Research Findings

We conducted two surveys to assess student experiences and gather self-reports of the activities using Piazza during the semester. In the first survey, most students (10/14) reported feeling positive about the pro–con debates. They reported that the debate format helped them structure their online discussion. Being assigned a pro–con position to develop arguments helped them think about issues more critically: "*having a predefined demarcation between the two sides in the debate contributes to structure, and that arbitrary assignment encourages greater mental flexibility and a better appreciation of the argument as a whole*" (P1).

One role the Piazza debates played in the students' learning was as a sort of warm up or preparatory exercise for the face-to-face in-class discussion. Nine of 14 students reported that constructing pro–con propositions in Piazza helped them to be more engaged in class: “*Piazza sets the stage for that day’s discussions… [Students] are able to prepare in advance and think about what they want to say in class that day*” (P14). Because of this advance preparation, the classroom discussions could be “*fast-pace and interactive*” (P6), could “*provide new or interesting points that complement the Piazza discussion*” (P1); “*classroom discussions definitely expand piazza points and further the arguments and analysis*” (P11). Indeed, students reported seeing the Piazza debate activity as a forum for initially working out arguments they expected to return to and develop further: “*I see that it is ok to post mere starting points as the real thoughtful discussion will follow [in class]*” (P2).

In the second survey, 13/13 students reported having developed better critical thinking skills. They perceived themselves to be more motivated to think critically while evaluating arguments: “*It motivates you to read much deeper into the author’s arguments to provide evidence and sound logical reasoning to support better either the con or pro position*” (P9). Students reported challenging their own existing beliefs: “*After reading Upcycle, I realized that I held the blatant assumption that you could only decrease how badly a product affected the environment was wrong*” (P7). They reported building on their peers’ contributions in formulating their own arguments: “*This method motivated me to think differently about reading a book, grasping its contents and restating them by providing me with the diverse viewpoints of my classmates*” (P14).

Students reported that the dialectical constructivist activity motivated them to consider sources beyond the particular assigned book when analyzing an issue. “*This learning approach motivated me to look for outside sources not just things from the book*” (P8). Students also reported broader cognitive impacts of thinking critically: “*I was able to see an issue from more than one perspective. This broadened my horizon as I realized there are more than one ways to approach a particular concept*” (P14).

Students reported that the Toulmin tags were useful to them in structuring their argumentation. However, students primarily used only a subset of the rhetorical categories. The fact-oriented tags evidence and backing were used eight times more than the tags qualifier and synthesis. Students’ arguments showed some confusion about less frequently used categories. For example, they conflated the relationship of backing to warrants with that of evidence to claims (Carroll, Wu, Shih, & Zheng, 2016).

Students also made use of Piazza’s “follow-up discussions” forum to continue developing or debating issues; in the first survey, 12 of 14 reported that follow-up discussions allowed them to elaborate the pro–con analysis: “*When posting follow-up posts I’ve found that I’m usually building upon the discussion by trying to bring something new to the table that supports one position or another*” (P6).

2.1.4 Discussion

This study showed how dialectical analysis of issues into pro and con positions backed by evidence could engage students and help them develop critical thinking skills. Students found the Piazza debate engaging and beneficial with respect to learning and practicing critical thinking skills. They reported that this dialectical learning activity helped them to have better discussions with their team members and prepare for class. They appreciated critical thinking as a way of learning.

Students reported an improvement in their own critical thinking skills through participation in this activity. Consistent with this self-report, we observed that student teams used a more sophisticated strategy for con arguments in the second half of the semester, developing more coherent arguments; not merely responding point-by-point to pro positions. Students were able to use the tags as a cognitive scaffold to produce fairly complex arguments. Our analysis of individual argumentation showed that students were able to create coherent and dialectical analyses, including tradeoffs and rebuttal arguments, often citing evidence outside the course material. Critical thinking also became more of an explicit topic discussed by the students with the instructor and among themselves. These results are encouraging. However, they need to be replicated and extended beyond our single class and instructor.

Our reappropriation of Piazza as a prototyping medium for this project was successful in that the dialectical learning activity we created engaged and benefitted the students. Piazza also functioned as a design research prototype. Pro–con arguments can be initiated by identifying either a pro or con position, but question–answer dialogues (as in Piazza) are always initiated with a question. Identifying this contrast led us to imagine a design different from Piazza, in which pro and con propositions could be posted in any order. For further details, see Carroll et al. (2016).

2.2 *Critical Thinker in a Remote User Study*

Inspired by the case study of using Piazza to scaffolded Pro and Con activity, we further developed the following design rationales to guide our design of Critical Thinker. Our Critical Thinker tool supports synchronous collaborative awareness using multiple synching mechanisms, with the goal of minimizing wasted or duplicated effort, and thus encouraging a free-flowing dialectical process. In the remainder of this subsection, we report a preliminary investigation of how these features are perceived and used for argument development (Sun, Yuan, Rosson, Wu, & Carroll, 2017).

2.2.1 Design Rationale for Critical Thinker

In our prior work, we appropriated Piazza to support a dialectical constructivist learning activity (Carroll et al., 2016), and further identified specific ways our implementation of the dialectical learning activity, including the Piazza prototype, could be improved:

(1) Piazza employs an awkward approach to collaborative editing. Individual users edit local buffers, and must manually execute a "save" in order to share their con-

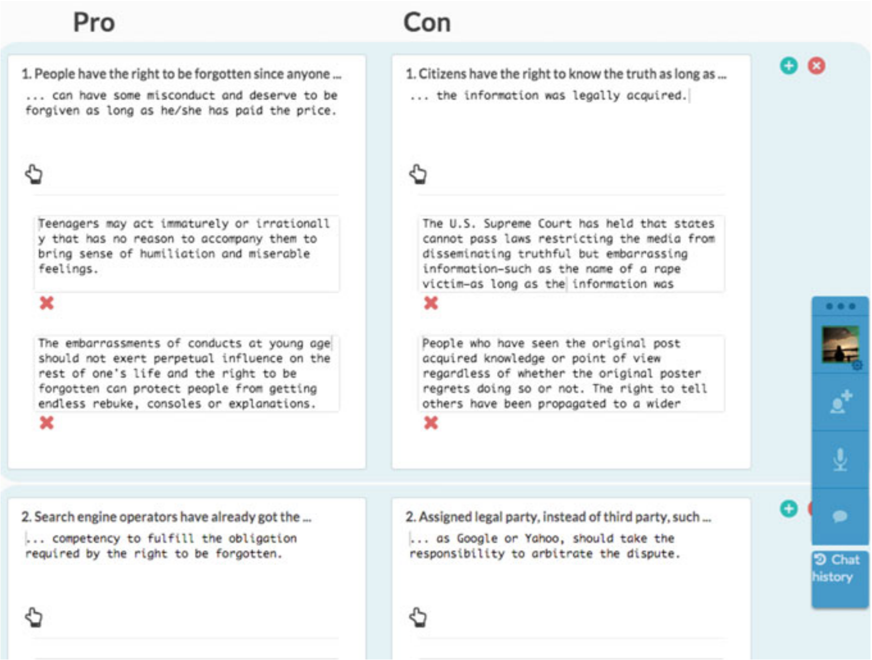
tributions. This can lead to conflicts as various collaborators edit and save their local buffers. Students are accustomed to collaborative infrastructures that automatically push edits, such as Google Drive's suite of web-based tools. Indeed, we found that quite a few of our students were already regular users of other tools. These pre-existing practices plus concerns about Piazza's manual "save" led students to collaborate with other tools and later paste their results into Piazza. We thus leveraged synchronous editing in combination with instant messenger tool in our own system to facilitate efficient collaborative work and communication in the development of arguments.

(2) Posting a question—placing text into a question pane in Piazza—causes the associated answer pane to display. This makes sense for question-answer discourses. One needs a question in order to create an answer. However, in pro–con discourses, it is reasonable to initiate argumentation identifying either a pro or con proposition. In reappropriating Piazza, we suggested to students that con teams could initiate an argument by posting a "pro-stub", which is a placeholder text in the question pane, to display the associated answer pane for their con proposition. Later, members of the pro team could edit the stub text to post their pro position. A better solution would be to display the entire pro–con pane structure permanently so as to queue students as to the significant components of the activity.

(3) The imbalanced use of and confusions about Toulmin tags in structuring dialectic learning led us to consider taking a simpler approach to the logic of argumentation, focusing only on the most basic distinction in argumentation, namely, the distinction between claims and support for claims.

(4) Piazza aligns question and answer panes vertically, graphically reinforcing the Q/A workflow of articulating questions before answers. This vertical alignment seems less appropriate for pro/con analysis. Indeed, we found that students developed an increasingly autonomous approach to con arguments over the course of the semester. In this approach, the con position did not reply to existing claims in the pro position. Instead, it developed independently. This may not be a problem, but it diminishes the extent to which the pro–con argument is substantively dialectical. This led us to consider aligning the pro and con text panes horizontally; to graphically emphasize to the students the possibility of constructing an explicit dialectic.

In contrast to the sequential and vertical layout in Piazza, we aligned pro and con panes horizontally (Fig. 1) to encourage dialectical argumentation. Users can open support panes directly beneath pro and con panes by clicking on the "+". The support panes contain evidence or other backing for the pro and con claims. Dialogue is supported semi-synchronously during via an instant message pop-up window. The resulting conversation is also archived for review during argument construction.



1. People have the right to be forgotten since anyone ...

... can have some misconduct and deserve to be forgiven as long as he/she has paid the price.

Teenagers may act immaturely or irrationally that has no reason to accompany them to bring sense of humiliation and miserable feelings.

The embarrassments of conducts at young age should not exert perpetual influence on the rest of one's life and the right to be forgotten can protect people from getting endless rebuke, consoles or explanations.

1. Citizens have the right to know the truth as long as ...

... the information was legally acquired.

The U.S. Supreme Court has held that states cannot pass laws restricting the media from disseminating truthful but embarrassing information-such as the name of a rape victim-as long as the information was

People who have seen the original post acquired knowledge or point of view regardless of whether the original poster regrets doing so or not. The right to tell others have been propagated to a wider

2. Search engine operators have already got the ...

... competency to fulfill the obligation required by the right to be forgotten.

2. Assigned legal party, instead of third party, such ...

... as Google or Yahoo, should take the responsibility to arbitrate the dispute.

Fig. 1 User interface design for Critical Thinker: Pro and Con text panes are horizontally aligned. By clicking on the + icon, users can expand and populate a support pane with evidence or backing for a pro or con claim, directly beneath each pro and con pane

2.2.2 Method

We asked participants to engage in a learning activity using Critical Thinker, after which they completed a post-study feedback survey. Our post-session survey probed reactions to Critical Thinker using open-ended questions from multiple angles, including the structure of argument input, reactions to several specific features (e.g., side chat and awareness support), general ease of learning, overall fit of the system to the activity, and suggestions for improvement. We adapted the instrument from prior Piazza research that was also studying dialectical thinking, to gauge design progress. 28 participants were formed into 14 dyads and randomly assigned to eight "Pro" groups and six "Con" groups. For the current chapter, we focus on the qualitative feedback gathered in the post-task survey. We carried out a thematic analysis of these responses to examine reactions to the design features, particularly the argument structuring and synchronization mechanisms.

2.2.3 Findings

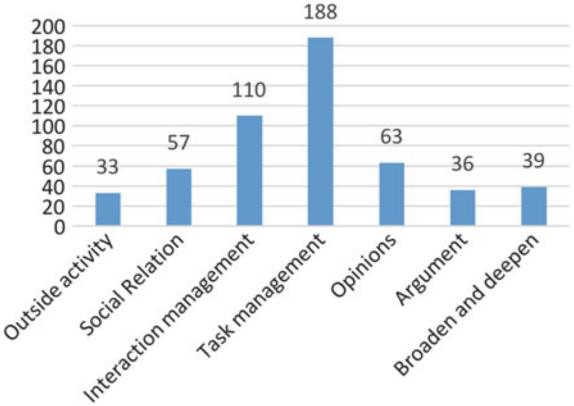
Structurally, the juxtaposed structure of pros and cons seemed to help students compare and contrast arguments. Eleven users noted that exposure to the opposing arguments was useful. "*Visually dividing the pros and cons*" in a horizontal manner was considered as efficient, and it provided "*an easy experience to formulate good ideas.*" To be more specific, participants found that the display allowed them to examine the value and coherence by reference to the competing argument, so that more balanced and responsive viewpoints could be developed. Meanwhile, the display was also reported to reduce the time spent on grasping the core of an issue and different aspects of it.

> My first approach was to just use the information from the articles to form Pros. However, I read the existing Cons and tried to view them in a different perspective to form a Pro. (P17)

To characterize how the participants made use of the online instant messenger in the process of developing collaborative argumentation, we applied the analytic framework of Rainbow to delineate communicative acts in collaborative argumentative tasks (Baker, Andriessen, Lund, Van Amelsvoort, & Quignard, 2007). Rainbow consists of outside activity, social relation, interaction management, task management, opinions, argumentation, broadening and deepening arguments. Two research assistants outside of our project coded the conversation dialogues for all the sessions. The inter-coder reliability Cronbach's alpha was 0.855.

A total of 526 messages were generated in the 14 sessions and shed light upon how communication occurred during real-time collaborative argument-making tasks (see Fig. 2). Most of the interactions were aimed at task management (36%) or interaction management (21%). It was reasonable for the participants to exert efforts in keeping the task on track due to distributed collaboration and time limit for the study. Messages directly about argumentation as well as linking arguments to broaden and deepen the discourse constituted 14% of the discussion; these comments were

Fig. 2 Coded chat messages based on Rainbow Framework



greatly appreciated by the participants because they led to in-depth collaborative argument development.

> I made use of the chat messages by asking questions in order to understand our argument more in depth. It helps when trying to come up with a strong argument. (P11)

A majority of participants commented that chatting helped them develop arguments, especially in terms of formulating and expanding ideas. Five participants said that they negotiated with their partners to affirm the appropriate wording, as well as the relevance and validity of arguments.

> We communicated every time we typed a claim. We wanted to be sure that each claim was legitimate, on topic, and not counter-productive. (P26)

Other scenarios for students to use online chatting include seeking clarifications from the administrators, coordinating efforts (call for help), distributing work, and maintaining group awareness.

A derivative of the synchronous online chatting is the record provided in the Chat History Browser. Twelve participants said that they utilized chat history at least once, to review or pick up their collaborative work because the chat history provided useful information grounding for collaboration.

> I went over it so I could get my facts straight and find the quotes we were using. It helped so I did not have to go back into the document to find the information. (P11)

Only 6% (N = 33) of the messages fell in the category of outside activities, and 11% (N = 57) of the messages had social purposes, including initial greetings, compliments, and expressions of gratitude. Informal scrutiny of messages for external activities revealed that most of the conversation were driven by the curiosity about their partner and attempts to build social relationships during the interaction, such as jokes, self-disclosure about off-line identity. We observed that rapport building was especially helpful in fostering group cohesion if it happened at a later stage of the task. However, too many off-topic chatting at an early stage in this short-term task could distract users from committing to the task, which were not appreciated by their partners.

Critical Thinker allows users to revise each other's work. Thirteen participants identified co-editing or revising as a salient feature for collaboration. Seven participants pointed out that they used revisions to convey disagreement in a less intrusive way that would have been experienced in the chat. The capability to revise each other's text in a synchronous workspace complemented the chat in a way that minimizes possible conflict or tension between collaborators. It also can offer additional task-related information without needing explicit (dialogue-based) coordination.

> We both revised each other's input, but we did not converse very much via instant message. I feel like this is because we did not know each other, therefore we did not feel comfortable enough criticizing each other's ideas. (P15)

The character-by-character synchronicity of text editing makes it possible to construct arguments together at a fine-grained level. However, it was rare for partners to edit the same input box at the same time.

The said phenomenon contradicts previous findings in which users were observed to suffer from losing their editing efforts without knowledge of their partners' working focus and context. However, such confusion was enlightened as other design features were considered. As seven participants pointed out, additional contextual cues, such as cursor updates, enabled dyad members to be aware of their partners' local context and activities. The knowledge about what others are working with at the moment suggests what action was needed so that redundant work can be avoided. Having the idea of what has been done enables users to coordinate on resources and to fully take advantage of each other's intellectual efforts towards the shared objective of task completion.

> I made use of my group member's cursor so I could see which topic he was working on and I could work on a different one. (P23)

Social presence is indicated through a color-coded dot (green is used to show being online and active) on the right pane of the screen, as well as keyboard input status showing when a partner is engaged in writing. These indicators were also appreciated for they reassured them about their partner's collaboration engagement.

2.3 Critical Thinker in a Face-to-Face Classroom

2.3.1 Participants

The context for this study was a first-year undergraduate honors seminar "Information, People, and Technology" with an enrollment of 19 students. The class is a general education course for honors college students at Pennsylvania State University, and also serves as the entry-point course for an interdisciplinary undergraduate major in Information Sciences and Technology (IST). Four of the students were indeed enrolled in the IST major, and six others joined that major during the course. Four of the students were majoring in engineering; ten of the students were majoring in liberal arts (including the six who subsequently changed to the IST major); one was majoring in communication studies. Six of the students in the class were female (including two liberal arts majors, the communications major, and three who changed into IST during the semester). The students were organized into four teams, before meeting the instructor in the first class, to maximize diversity with respect to gender and major.

2.3.2 Research Design

During the first class meeting, the instructor demonstrated Critical Thinker and presented the right to be forgotten example (as illustrated in Fig. 1), emphasizing the concepts and utility of critical thinking in general, of pro–con dialectics specifically, and of distinguishing claims from support.

Table 1 Critical thinking course activities

Topics	Semester weeks
The future of work	Week 1
Reviving community networks	Week 2
The glass cage	Weeks 5 and 6
Uncharted	Weeks 7 and 8
The app generation	Weeks 9 and 10
The upcycle	Weeks 11 and 12

Subsequently in the course, students worked in teams to collaboratively analyze two lectures presented by the instructor. These lectures addressed technological and social factors shaping the future of human work, and socio-technical approaches to enhancing community in American society; both lectures were designed to be argumentative. The students' Critical Thinker analyses took place during the week following each lecture, mostly out of class. Instructor feedback on these first two activities focused primarily on formative guidance and encouragement of the students in identifying and clarifying pro and con arguments, as opposed to summatively assessing the quality of their analyses and argumentation (Scriven, 1967).

The major dialectical constructivist activities for the course were analyses of four argumentative books: The glass cage: How our computers are changing us (Carr, 2015), Uncharted: Big data as a lens on human culture (Aiden & Michel, 2014), The app generation: How today's youth navigate identity, intimacy, and imagination in a digital world (Gardner & Davis, 2013), and The Upcycle: Beyond sustainability—Designing for abundance (McDonough & Braungart, 2013). These books were selected because they present specific and provocative theses about technology, information, and people without attempting to present a balanced case.

The six course activities using Critical Thinker, and their sequencing and duration during the 15-week semester, are described in Table 1.

Students worked in the same four teams throughout the semester. The six collaborative pro/con argumentation activities employed a jigsaw design (Slavin, 1980) in which different teams made distinct but interdependent contributions that were pooled and integrated at the class level. For any given activity, one team argued for the pro position (supporting and developing the authors' argument), and a different team took the con position (challenging and rebutting the authors' argument). A third team was given the responsibility of summarizing the pro–con debate, including the class discussions evoked from Critical Thinker analyses and in-class presentations. Members of the two teams that did not prepare pro or con positions were also asked to contribute to class discussions, and specifically to ensure that the pro and con teams made clear and compelling arguments.

For the first two course activities using Critical Thinker, and based on class lectures, each of the four teams played either a pro or con role, preparing their position in Critical Thinker, and then presenting in class. All students subsequently wrote a short synthesis paper for each of these first two activities, based on the Critical Thinker analyses, and on the class discussions.

For the 4 book analyses, team role assignments were permuted so that each team played the pro role once, the con role once, and the discussion synthesis role once, in this case writing a short team paper synthesizing the Critical Thinker debate and class discussion that was shared with other members of the class. The six dialectical learning activities were a significant component in the students' course grade.

Surveys

We conducted two surveys to assess student experiences and gather self-reports of the activities using Critical Thinker during the semester. The first survey was instrumented about half way through the semester, after the students completed analyzing *The Glass Cage*. We asked the students how they organized team participation in Critical Thinker argumentation, how those activities supported their learning, how their approach to the Critical Thinker activities may have evolved, how in-class discussions were affected by Critical Thinker work, and how they experienced interactions with the Critical Thinker software. 13 out of 19 students responded to the first survey.

One of the objectives of implementing a dialectical learning model is to encourage students to adopt, enact, and reflect upon dialectic and critical thinking skills. Based on student feedback from the first survey, a second survey was instrumented toward the end of the semester, after the students completed analyzing the fourth and final book, *The Upcycle*. The second survey focused specifically on how students perceive the Critical Thinker-based dialectical learning activities in relation to their own critical thinking skills. Fourteen out of 19 students responded to the second survey.

The survey items all consist of short open form questions. The surveys were analyzed by the authors, who iteratively grouped the answers into self-similar categories until the groupings stabilized in agreement (Strauss, 1987). Because of the small number of students in the course, we only report these data descriptively, characterizing the most salient groupings through quoting typical responses, and citing overall counts.

2.3.3 Findings

Based on two surveys distributed across the semester, students reported that the activity helped them structure their discussions and prepare for and engage in face-to-face class discussions. They felt the activity improved their critical thinking skills.

In the first survey, several students used Critical Thinker to cement their reading by articulating what they have learnt from books and also by checking others' posts (e.g., P2, P5). Further, the simplified argument structure also highlighted the essence of creating arguments, that is the grounding of a claim, as students felt obliged to offer evidence or examples as opposed to merely stating claims "*as if they're true*" (P8). Such obligation may arise from the easy-to-operate button for interaction with the system, or from the opposing standpoints that pre-exist and invite corresponding responses. Out of the pro and con development activity, five participants commented that they were better able to think deeper, and to form more balanced and fuller views with the help of developing Pros and Cons. For example, P7 said, "*I think it is a good tool for learning because you can really see a pro and how it relates to its corresponding Con laid out right next to each other. It has affected me because I am better able to recognize both sides to an issue and understand it more fully.*" In addition, four participants found that the pro and con horizontal structure emphasizes the contrasting perspectives of the same matter so that it creates "*a sense of competition*" among different groups (P2). As a result, P10 often found himself more careful with the logical structure in the process of argument development: "*I found it called for more in-depth research to craft arguments that cannot be easily refuted.*" Moreover, although P6 thought her skills in "*arguing*" improved, she expressed concerns with overuse of critical thinking to the extent that hinders her from learning the "*actual information we were to have learned from the lectures/books.*" In contrast, P5 appreciated creating cons as it "*helps develop our critical thinking abilities because we have to extend the discussion beyond what's explicitly mentioned in the text.*" Based on dialogic constructivism, knowledge needs to be decomposed and constructed for learners. Therefore, P6's concerns and P5's appreciation in developing counterarguments again demonstrate the scaffolding functions of Critical Thinker in justifying and encouraging critical thinking in the pedagogical practices and technology design.

In the second survey, most students reflected on their learning practices and reported to have strengthened their critical thinking skills more than reading text, or in P1's words, "*more than reading and regurgitating*". For instance, P4 appreciated being forced to read with the purpose of harvesting information for or against a claim, especially for Con arguments: "*This was pretty easy for the pro points but much harder for the con arguments because I found myself just 'zoning out' and just reading. It was a challenge to stay focused on tearing apart the argument presented because naturally the authors would do their best to hide the flaws.*" Despite the overall positive effect of using Critical Thinker to become more of a critical thinker, pre-assigned groups of Pro and Con who are in charge of posting in Critical Thinker may limit full participation at the entire class level. In contrast, students perceived benefits from in-class discussion, where they may pick up more critical thinking skills: "*I did not find Critical Thinker too helpful. It only helped me think a bit more critically when I was actually the one posting. I feel like my critical thinking skills developed most during class discussions, and the discussions themselves made me a better critical thinker and skeptical person.*" (P5).

In total, 31 sets of arguments are developed collaboratively both within-group and between group. The horizontal alignment of pro and con analysis yields very comparable argumentations on both sides in terms of argument length and quantity. A closer investigation in terms of the content for each pair of pro and con was conducted, revealing a variety of strategies students adopted in reaction to the pro arguments. Self-standing, or independently structured arguments were also found in Critical Thinker, but appeared less apparent than the tendency found in Piazza-supported activities. Instead, new patterns of collaborative argumentations emerged with the presence of pre-existing arguments listed on the left of a horizontal side-by-side textual structure. First and foremost, students in the Con Group took advantage of the scaffold in Critical Thinker when developing a dialectic, paying close attention to the arguments developed in the Pro Pane. Specifically, students analytically examined what is articulated from the opposing point of view, and decomposed the pro argumentation for inspection, attacking the validity of others' arguments from various angles, such as assumptions, boundary conditions, accuracy of grounds used to back the propositions. As a result, con propositions are often phrased as purposeful rebuttal against the standpoints, or grounds from the other side; con arguments are sometimes framed from a different perspective towards the same issues, but complete the consideration of a particular act, artifact or phenomenon with alternative measures or possible consequences. Some enumerated counterargument with a list of potential drawbacks or alternative solutions, with few or no anaphora to the pro positions; some quoted the arguments in the pro, but pointed out the limitation of saying so; others admitted the pro arguments conditionally, but asked for more clarification against the difficulties facing the proposed means. However, we also found sometimes con group addressed the backings in the pro group in great detail, even to the extent that they sometimes forgot to defend their own standpoints, regardless of whether they have proposed an entirely different point in the leading position container.

Second, after we simplified the argument ontology following Toulmin structure, students demonstrated capability in constructing arguments associated with multiple supportive backings and warrants. In particular, average numbers of backings for each pro and con position are 2.68 and 2.23, respectively. Indeed, students ground each position with elaborative arguments to support a standpoint or rebut against the opposing arguments. The adding backing buttons seem to be easy to use for students to build consistent backings one by one since we did not find any cumbersome chunk of backings in one single pane. Pro group often centered their backings around the materials presented in the text, which yields quotes inside the textbook and the examples from their readings. Likewise, con group often made anaphora over the examples to reason about what is missing or taken for granted.

Third, con groups not only seem to address Pro arguments point-to-point regarding the subject matter and semantic meaning but also appear to compete against one another in terms of the quantity they can enumerate with. Among 31 sets of argumentations, there are 8 sets of arguments on a par with each other in terms of the number of supporting backings, 8 con argumentations that outnumber backings of pro, and 15 pro argumentations whose backings outnumber that of con group. Therefore, we can see that con group undertook more than a passive, or reactive role against the existing arguments, but actively develop their own arguments.

Fourth, as the dialectics are going on, con groups often ended their remarks or arguments with a question, instead of statement, which seems to invite continuous conversations from the pro group. Such inclination with continuous discussion may be encouraged by the dialectical constructivist scaffold in Critical Thinker: students on either side of the horizontal discussion pane are expected to consider the opposing side, since both sides are aligned in an equivalent and balanced structure for comparison, contrast, and reflection. It is also beneficial to inspire further thinking and invite more responses from other students based on the rationale of instruction design to promote a larger discussion over the entire classroom.

2.4 Crowdsourcing Dialectics on Kialo

In this study, we used participant observation in an online peer production community called Kialo, which enables users to construct elaborate pro/con arguments about a topic of their choice. Similar to other peer production communities, Kialo has admins and editors (hereafter: moderators) who oversee debates and participants. Moderators are responsible for evaluating claims for inclusion in a debate, editing claims that have been "flagged" as problematic, and refactoring debates as they grow.

2.4.1 Research Approach

In line with existing studies of online communities (Boellstorff, Nardi, Pearce, & Taylor, 2012), we made the decision to use virtual ethnographic methods to explore moderation practices on Kialo. We are engaged in ongoing (ten months) participant observation (Beck, Neupane, & Carroll, 2018), which means that we are active writers and moderators in several debates on Kialo.

We have been developing a thick record (Carspecken, 1996) of our interactions on Kialo. This consists of (1) low-inference summaries of interactions and experiences on Kialo and (2) relevant, publicly visible user-generated text on Kialo. This publicly visible text comes either from a discussion chat or a claim chat. The discussion chat facilitates talk about high-level issues pertinent to a debate (e.g., are there too many top-level claims, does the main thesis need to change), onboarding new participants (e.g., by explaining to them the nuances of a debate, how Kialo works, etc.), as well as casual talk (e.g., who has been on vacation/holiday recently, whether someone has gotten busy at work, and so forth). Claim chats tend to be focused more so on the issues with a particular claim (e.g., whether it is unclear, unsupported, or irrelevant), though people discuss higher-level issues here, too. Both discussion and claim chat records are publicly visible, and we collect and organize them as part of our thick record.

We iteratively read and discussed our thick record, which drew our attention to the way moderation practices changed when Kialo rolled out design updates. In particular, we became interested in the ways that moderators came into conflict with each other as a result of those changes. This led us to examine our thick record through the lens of conflict and to consider the ways in which conflict could be said to detract from or contribute to moderation practice. We continued our observations as we performed data analysis, and became aware of the importance of claim vetting, which, in turn, led us to re-examine our data in terms of how the conflict between moderators affects claim vetting.

2.4.2 Research Findings

First, we describe how claim vetting involves argumentation between moderators. Second, we describe how constructive dialogue between moderators can produce higher quality claims. Higher quality claims can mean that the claims are clearer, that they have stronger support, or that they become more relevant to a parent claim or main thesis. Although the interactions and text we describe are publicly visible on Kialo, we have changed all user names and edited text in an effort to maintain user privacy.

Vetting Claims Involves Arguing with Other Moderators

Conflicts can arise when one moderator initiates a discussion about a claim and another moderator accepts it before there has been any resolution to the discussion. Since Kialo does not have an official policy on conflict management, moderators take different approaches in response to what they see as a conflict.

An illustrative case in the climate change debate, for example, played out between several moderators across multiple claim chat threads. It began with what one moderator perceived as a breach of protocol by another. @sodanotpop had been workshopping a suggested claim with an author when another moderator, @blueteam, accepted the claim into the debate. @sodanotpop subsequently flagged the claim and engaged @blueteam: "*[It] was not appropriate to accept a suggestion still under discussion. I engaged the author in order to strengthen it before accepting it into the debate*." This comment initiated a lengthy argument that played out in three separate claim chat threads, which meant that these two moderators were moving to different claims in the debate arguing with each other about the proper protocol for collaborative claim vetting.

Some of this argumentation was pertinent to the claims themselves. For example, @blueteam discussed newly provided support as justification for accepting claims. "*I accepted it because the author's claim was cited as unsupported, they then supported the claim so i marked it as supported.*" They questioned the grounds for other claims. "*Where is the evidence or anything else substantial that backs up this claim?? there isn't any.*" Similarly, @sodanotpop pointed out that "*the claim contains a link to scientific work that has been disproven (shown to be false) by other members of the scientific community.*"

However, they also argued over how to go about collaborative claim vetting. Whereas @blueteam felt justified in accepting a claim that had been marked and was apparently in the process of being workshopped, @sodanotpop believed that it was inappropriate for another moderator to accept a claim that they were workshopping. @sodanotpop could have been echoing the perspective of another moderator in the debate, @libre, who, in a separate thread, called out a user for accepting a claim under discussion. "*[I] think it might have been better to not accept this when @saskatoon @sodanotpop and me discuss it.*" This comment did not lead to a long argument between moderators. In fact, the person who accepted @libre's claim did not respond again in the thread.

While there can be drawbacks to moderators having different points of view, it is not necessary to frame points of view as liabilities. There are examples of how different—even opposing—points of view can be used to strengthen claims and debates on Kialo. On the other hand, there appear to be more scenarios involving clashing points of view that devolve into arguments that lead to no concrete improvements in a debate. In some cases, arguments have concrete, negative consequences: participants may withdraw from a debate or decide to stop using Kialo altogether. A key seems to be managing different points of view to facilitate constructive dialogue between adversarial points of view.

Constructive Arguments Yield Concrete Changes

Dialogue is the primary way moderators resolve issues pertinent to the overall structure of a debate, to particular (problematic) claims, and to moderation practices. While it is possible, in our experience moderators rarely work in isolation. In fact, the two most important elements of the interface might be the discussion and claim chats since these provide the forums for moderator dialogue. Two important features of these chats are: (1) they are public and thus visible to the entire Kialo community and (2) they are continuous. Public visibility may strengthen civility between participants on the site, and a living historical record provides insight into how ideas may have evolved over time.

There are many examples of dialogue between moderators and writers resulting in concrete improvements to the clarity, relevance, or grounding of a claim. These dialogues tend to include civil language and a respect for other perspectives and approaches—even those that deviate from site-wide conventions for conduct. In a debate about gender as a social construct, for example, someone changed the form of the main thesis without consulting others who had been actively working in the debate. This resulted in a discussion of the merits of the change and, ultimately, a decision to revert the thesis back to its previous form:

> **@originator:** I'll tag @jolene @abcdefg and @grasshopper to see if they agree with the changes.
>
> **@jolene**: Some of the reasons expressed have a point. But, I feel the first formulation was clearer for most readers (with little background knowl) and as objective as possible
>
> **@abcdefg**: I think the current wording communicates that gender and sex are the same, and the suggested claims just now coming in reflect this.
>
> **@abcdefg**: I'm going to re-draft it similar to the original or now; we can continue discussing this to get something stronger. Hope that's okay!

Kialo currently hosts several debates addressing potentially divisive issues, such as the current "stand or kneel" NFL controversy in the United States, abortion rights, and racial profiling. It is understandable that participants in these debates, including moderators, would have strong perspectives on these topics. Furthermore, it is also understandable that these perspectives would in some way inform their interactions with others on the site. For writers, this might mean posting more “pros” in support of a topic in accordance with their views. For moderators, this could mean holding certain sides of a debate to higher standards as one debate participant suggested: “*This is a clearly biased discussion. You have multiple pro claims that have no support and most of the skeptical ones are challenged repeatedly (to the point that the average contributor would give up).*” Such bias is perceived as a liability on account of how it excludes certain perspectives from the debate.

3 Discussion and Conclusion

In this chapter, we reflected on our efforts to facilitate learning through explicit construction of dialectics. We did this by presenting three case studies. First, we discussed our reappropriation of Piazza to facilitate debate in a freshman honors seminar. We found that students had a positive view of the debate format and perceived that it helped improve their critical thinking skills, and made face-to-face in-class discussion better. Next, we described the design and deployment of Critical Thinker, a pro/con debate tool. We found that students are more inclined to embrace a balanced view with active dialogical constructive thinking process provided with a horizontally aligned argument pairs, and that they might need a more integrated environment to engage discussions with peers remotely (e.g., GroupMe) and co-locally (e.g., classroom). Finally, we summarized findings from our long-term participant observation of Kialo, a novel online peer production community for building pro/con debates. We found that moderators often engaged in meta-arguments with each other both about the content of a debate and about the practice of debate moderation. We identified “constructive arguments” between moderators as those that yield concrete changes to a debate, and we generated implications for the design of pro/con debate platforms to help keep arguments focused and constructive rather than counterproductive. Some lessons learned are summarized in Table 2.

Table 2 Lessons learned from the three case studies

– Constructing dialectic analyses was experienced as meaningful learning activity by first-year honors students
– The analyses focused on and improved subsequent in-class discussion as experienced by students
– Students felt that building and discussing dialectical analyses improved their critical thinking skills
– Claim vetting can be framed as a collaborative, group activity that can lead to new insights about the overall structure and quality of a dialectic
– Personal beliefs and values inform pro/con argumentation, and students may benefit from the role these things play

3.1 Supporting Students in Dialectical Analysis and Learning

We studied online platforms for dialectical analysis and learning. Each platform focused on helping people develop pro–con analysis of debatable issues. The platforms varied in how they support explicit tinkering with argumentation. For example, we observed that people constructing dialectical arguments use pro and con arguments as mutual cognitive scaffolds. They reacted to pro claims by articulating con claims, and vice versa. They iteratively explored and refined arguments, including attending to how constitutive points were emphasized and ordered. This raises a series of design challenges as to how such tinkering can be facilitated and strengthened.

Our reappropriation of Piazza presented unstructured text panes for pro and con arguments. To refer to subpoints, students used indices, numbering the points to indicate which pro corresponded to which con. In Critical Thinker, we facilitated direct pro–con backtalk by horizontally aligning corresponding subpoints. This design decision made explicit indices unnecessary, and made it easier for students to see and tinker with arguments at the level of pro/con pairs.

Kialo facilitates tinkering with pro/con dialectics through mechanisms that support the recursive development of arguments behind every argumentative point. That is, every pro point and every con point can be backed with a pro/con analysis of that specific point, and every pro or con point also has a public forum in which authors discuss where the point should be positioned in the overall argumentative structure, and how it should be worded. These design elements are central to the dialectical practice of Kialo and are effective at evoking detailed tinkering with specific points. Public fora have as many as 100+ comments from moderators and writers regarding the quality of, or possible improvements to, specific pro or con claims.

Interestingly, Kialo does *not* support the horizontal alignment of corresponding pro/con points, such as what was used in Critical Thinker. On the other hand, Critical Thinker does not support the finer articulation of particular points in the argumentation, which is well developed in Kialo. Thus, we believe that a design incorporating both techniques might encourage sophisticated simultaneous tinkering both at the level of the pro/con pairs *and* at the level of the individual pro and con points.

Moreover, unlike Piazza and Critical Thinker, Kialo provides a way for debate participants to see how others have voted on the overall debate topic as well as on individual claims. By voting on a thesis or claim, participants articulate their "perspective" on a claim. A vote expresses whether a participant agrees, or finds convincing, a particular claim, but it does not capture the reasons why. Thus, participants remain unaware of the possible role their personal perspectives may play in dialectical reasoning. Viewing a particular thesis favorably may influence students' reasoning and participation, e.g., a person might be more likely to evaluate claims in favor of human influence on climate change if such claims align with their worldview. We are, therefore, proposing designing elements to bring about greater awareness the role personal values and assumptions play in pro–con argument tinkering.

3.2 Summary

This chapter identified challenges to the design and implementation of interactive systems for argumentation, and it suggested possible ways for educators, and designers of educational technologies, to address these challenges. Two cases illustrated ways of integrating interactive technologies into classroom activities such that they support more useful and engaging learning experiences. The third case drew attention to counterproductive discourses that can arise in interactive debate systems. It showed how these discourses are tied to human values and beliefs and motivated by interaction design, which reaffirm the need for multidisciplinary inquiry.

Our experiences with structured argumentation and debate activities suggest that developing and refining explicit arguments can be an engaging learning and problem-solving activity that directly facilitates the development of critical thinking skills. As such, this is an important direction for supporting learning in the digital world.

References

Aiden, E., & Michel, J.-B. (2014). *Uncharted: Big data as a lens on human culture*. New York: Riverhead Books.

Baker, M., Andriessen, J., Lund, K., Van Amelsvoort, M., & Quignard, M. (2007). Rainbow: A framework for analyzing computer-mediated pedagogical debates. *International Journal of Computer-Supported Collaborative Learning, 2*(2–3), 315–357. https://doi.org/10.1007/s11412-007-9022-4.

Beck, J., Neupane, B., & Carroll, J. M. (2018). Managing conflict in online debate communities: Foregrounding moderators' beliefs and values on Kialo. https://doi.org/10.31219/osf.io/cdfq7.

Boellstorff, T., Nardi, B., Pearce, C., & Taylor, T. L. (2012). *Ethnography and virtual worlds: A handbook of methods*. Princeton, NJ: Princeton University Press.

Carr, N. (2015). *The glass cage: How our computers are changing us*. New York: Norton.

Carroll, J. M., & Rosson, M. B. (2005). A case library for teaching usability engineering: Design rationale, development, and classroom experience. *ACM Journal of Educational Resources in Computing, 5*(1), Article 3, 1–22.

Carroll, J. M., Wu, Y., Shih, P. C., & Zheng, S. (2016). Re-appropriating a question/answer system to support dialectical constructivist learning activity. *Educational Technology Research and Development, 64*(1), 137–156.

Carspecken, P. (1996). *Critical ethnography in education research: A theoretical and practical guide*. New York, NY: Routledge.

Cho, A. (2013, June 14). Network science at center of surveillance dispute. *Science, 340*(6138), 1272.

Cooner, T. S. (2005). Dialectical constructivism: Reflections on creating a web-mediated enquiry-based learning environment. *Social Work Education, 24*(4), 375–390.

Dalgarno, B. (2001). Interpretations of constructivism and consequences for computer assisted learning. *British Journal of Educational Technology, 32*(2), 183–194.

Dewey, J. (1933). *How we think: A restatement of the relation of reflective thinking to the educational process*. Lexington, MA: Heath.

Gardner, H., & Davis, K. (2013). *The app generation. How today's youth navigate identity, intimacy, and imagination in a digital world*. New Haven: Yale University Press.

Herreid, C. F. (2004). Can case studies be used to teach critical thinking? *Journal of College Science Teaching, 33*(6), 12–14.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235–266.

Jonassen, D. H., & Kim, B. (2010). Arguing to learn and learning to argue: Design justifications and guidelines. *Educational Technology Research and Development, 58*(4), 439–457.

Kuhn, D. (1999). A developmental model of critical thinking. *Educational Researcher, 28*(2), 16–46.

Land, S. (2000). Cognitive requirements for learning with open-ended learning environments. *Educational Technology Research and Development, 48*(3), 61–78.

Land, S. M., & Hannafin, M. J. (1996). A conceptual framework for the development of theories-inaction with open-ended learning environments. *Educational Technology Research and Development, 44*(3), 37–53.

Land, S. M., & Hannafin, M. J. (1997). Patterns of understanding with open-ended learning environments: A qualitative study. *Educational Technology Research and Development, 45*(2), 47–73.

McDonough, W. & Braungart, M. (2013). *The Upcycle: Beyond sustainability--designing for abundance*. New York, NY: North Point.

Moshman, D. (1982). Exogenous, endogenous, and dialectical constructivism. *Developmental Review, 2,* 371–384.

O'Donnell, A. M. (2012). Constructivism. In K. R. Harris, S. Graham, T. Urdan, C. B. McCormick, G. M. Sinatra, & J. Sweller (Eds.), *APA educational psychology handbook, Vol 1: Theories, constructs, and critical issues* (pp. 61–84). Washington, DC: American Psychological Association.

Pavlidis, P. (2010). Critical thinking as dialectics: A Hegelian-Marxist approach. *Journal for Critical Education Policy Studies, 8*(2), 74–102.

Piaget, J., & Inhelder, B. (1969). *The psychology of the child*. New York, NY: Basic Books.

Rakes, G. (1996). Using the internet as a tool in a resource-based learning environment. *Educational Technology, 36*(5), 52–56.

Sanders, J. A., Wiseman, R. L., & Gass, R. H. (1994). Does teaching argumentation facilitate critical thinking? *Communication Reports, 7*(1), 27–35.

Schreyer Honors College, Honors Courses description. Retrieved January 4, 2016, from https://www.shc.psu.edu/academic/courses/.

Scriven, M. (1967). The methodology of evaluation. In R. W. Tyler, R. M. Gagne, & M. Scriven (Eds.), *Perspectives of curriculum evaluation* (pp. 39–83). Chicago: Rand McNally.

Slavin, R. E. (1980). Cooperative learning. *Review of Educational Research, 50*(2), 315–342.

Strauss, A. L. (1987). *Qualitative analysis for social scientists.* Cambridge University Press.

Sun, N., Yuan, C. W., Rosson, M. B., Wu, Y., & Carroll, J. M. (2017, July). Critical thinker: Supporting collaborative argumentation with structure and awareness. In *Proceedings—IEEE 17th International Conference on Advanced Learning Technologies, ICALT* (pp. 406–410). http://doi.org/10.1109/ICALT.2017.61.

Toulmin, S. (1964). *The uses of argument*. New York: Cambridge University Press.

Vivian, R., Falkner, K., & Falkner, N. (2013). Building consensus: Students' cognitive and metacognitive behaviours during wiki construction. In *Learning and Teaching in Computing and Engineering: LaTiCE 2013* (Macau, 21–24 March, pp. 154–161). Los Alamitos, CA: IEEE.

Vygotsky, L. S. (1978). Interaction between learning and development. In M. Cole, V. John-Steiner, S. Scribner, & E. Souberman (Eds.), *Mind in society: The development of higher psychological processes* (pp. 79–91). Cambridge, MA: Harvard University Press.

Chapter 4
Supporting Learning in Educational Games: Promises and Challenges

Valerie Shute, Seyedahmad Rahimi and Xi Lu

1 Introduction

Can playing digital games enhance learning? This rather general question has been investigated in many research projects over the past couple of decades using various games that support different competencies, such as visual-spatial abilities and attention (Green & Bavelier, 2007, 2012; Shute, Ventura, & Ke, 2015), persistence (Ventura, Shute, & Zhao, 2012), creativity (Kim & Shute, 2015), and civic engagement (Ferguson & Garza, 2011). Also, many research studies have used digital games to enhance students' knowledge about particular concepts like physics (Shute, Ventura, & Kim, 2013), mathematics (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Ke, 2008), and ecosystem science (Kamarainen et al., 2013). Most of the research on the effectiveness of digital games to support learning have shown positive results (Clark, Tanner-Smith, & Killingsworth, 2016; Gee, 2003; Ke, 2013). For instance, Clark and colleagues (2016) found, overall, a medium effect size in a meta-analysis comparing the use of digital games and nongame conditions relative to their effects on learning. The effectiveness of the games in supporting learning, however, depends on certain features of games.

As Shute and Ke (2012) pointed out, well-designed games include the following features: (1) ongoing interactive problem solving; (2) specific goals or rules which help the player focus and stay motivated to play; (3) adaptive challenges which keep the level of difficulty of the game in and around the outer boundaries of players' ability—as the player gains new skills and becomes more capable, the game's

---

V. Shute (✉) · S. Rahimi · X. Lu
Florida State University, Tallahassee, USA
e-mail: vshute@fsu.edu

S. Rahimi
e-mail: sr13y@my.fsu.edu

X. Lu
e-mail: xl14h@fsu.edu

P. Díaz et al. (eds.), *Learning in a Digital World*, Smart Computing and Intelligence, https://doi.org/10.1007/978-981-13-8265-9_4

challenges become more difficult; (4) control by the player of game play, the game environment, and/or the learning experience; (5) ongoing and timely feedback; (6) uncertainty, which makes the game interesting, entertaining, and unpredictable; and (7) sensory stimuli which refer to a system of various media, e.g., graphics, sound, and animation, as well as a possible storyline which can keep the player on edge and immersed in gameplay. Because games differ in terms of their quality, not all games can enhance learning, thus our focus in this chapter is on the effects of well-designed games as learning environments (Ke, 2016; Wouters & van Oostendorp, 2013) or as vehicles that can be used to enhance learning (Gee, 2003).

Well-designed games also benefit from particular learning theories (Gee, 2008). For example, when playing digital games, players are actively involved in solving specific problems (sometimes in collaboration with other players). In such cases, we can see the common elements of constructivist learning, collaborative learning, and situated learning theories (Bruffee, 1993; Lave & Wenger, 1991; Leemkuil & de Hoog, 2005). Moreover, the incentive systems embedded in the games (i.e., the reward and penalty system in the games; the collection of coins, trophies, badges) are supported by basic behaviorist learning theories (Skinner, 1978). Learning theories support how learning occurs in well-designed digital games.

Another important factor that makes digital games potentially valuable learning tools has to do with how popular they are among the people around the world regardless of age, gender, and ethnicity. For example, 97% of children and adolescents in the United States play a type of digital game for at least one hour per day (Granic, Lobel, & Engels, 2014), and 42% of Americans play video games regularly, or at least three hours per week (Entertainment Software Association, 2016). Why are digital games so popular? The short answer is that they are fun and often immersive (Prensky, 2001)—either played alone or with others. Specifically, playing well-designed games can lead us to a state in which we lose track of time, and experience strong positive feelings when solving difficult problems (“aha” moments). This state is called *flow*, introduced by Csikszentmihalyi (1990).

Learning scientists, instructional designers, and educators have reported the potential of digital games as learning tools to support various content knowledge (e.g., physics, mathematics, ecosystems) and various competencies (e.g., problem-solving skills, critical thinking, computational thinking, and creativity). As a result, new fields are emerging, such as game-based learning, game-based assessment, serious games, and educational games. However, the promises of digital games for learning can fall into the trap of “chocolate-covered broccoli” (Laurel, 2001). That is, digital games with poor integration of learning materials and supports can detract from the fun, disrupt the state of flow, and turn the game into just more instructional software. This issue of optimally integrating learning supports into educational games has caught the attention of researchers and game designers. Research on best practices of incorporating learning supports in digital games—without interrupting flow while maximizing learning—and research on the effectiveness of these learning supports can shed some light on answers to the how, what, when, and how much of providing learning supports in digital games.

The purpose of this chapter is to (a) define the most common types of supports and their effectiveness relative to learning, (b) present an example of our own work implementing a learning support system in an educational game, (c) discuss how we handled various challenges that we faced when incorporation learning supports in our game, and (d) suggest future research that can help pave the way for more successful educational games. In the following sections of this chapter, we will elaborate on each of these topics in order.

2 Common Learning Supports in Educational Games

In this section, we first look at the literature to see whether learning supports in educational games were effective or not. Then, we elaborate eight common learning supports used in educational games.

2.1 Are Learning Supports in Games Effective in Their Support of Learning?

As discussed in the Introduction, and based on a couple of decades of research in game-based learning, educational games are generally viewed as effective learning tools (e.g., de Castell & Jenson, 2003; Gee, 2003; Prensky, 2001). But what, specifically, is the effect of including explicit learning supports in these games? Wouters and van Oostendorp (2013) define such supports in educational games as comprising multiple methods and techniques that help to develop learners' cognitive activities during gameplay.

The literature on learning supports in learning environments in general is somewhat conflicted. Some researchers (e.g., Black & Deci, 2000) note that learning environments that allow for full autonomy (i.e., student control), without explicit supports, can be more engaging and effective environments than those without such freedom. Also, Clark et al. (2016) concluded from their meta-analysis that extra instruction (after gameplay, in the form of learning support) did not produce any significant learning differences between game and non-game conditions when compared.

More specifically, regarding educational games, other researchers (e.g., Wouters & van Oostendorp, 2013) have concluded that to keep novice players engaged with the game, it must include learning supports. That is, digital games are complex and challenging environments that demand a lot of cognitive effort, so without any supports, learners will likely get stuck, frustrated, disengaged, and thus stop playing (Wouters, van Nimwegen, van Oostendorp, & van Der Spek, 2013). In that case, learning outcomes may be in jeopardy. Therefore, including supports in educational games increases the odds of improving learning. However, integrating supports into educational games is not easy, especially if we want them to not disrupt the flow.

Regarding the effectiveness of various learning supports in educational games, Wouters and van Oostendorp (2013) conducted a meta-analysis on the topic. They selected 29 studies (with 3,675 participants) and computed 107 pairwise comparisons to investigate the effectiveness of learning supports in educational games. They found a positive and moderately weighted effect size of $d = 0.34$ ($z = 7.26, p < 0.001$) which suggests that the use of learning supports in games can, in fact, improve learning. Furthermore, Wouters and van Oostendorp identified 24 different types of learning supports and grouped them into ten categories. We briefly discuss eight of the more common types of support used in educational games.

2.2 Common Types of Learning Supports Used in Educational Games

There are multiple kinds of learning supports that have been used and tested in educational games and other kinds of learning environments. Here, we describe a set of eight different supports that are most commonly used in educational games (Wouters & van Oostendorp, 2013): reflection, modeling, advice, collaboration, interactivity, narrative elements, feedback, and modality. Wouters and van Oostendorp included two other categories: personalization (e.g., personalized messages), and other (e.g., goal direction, background information, and cues). We chose not to include these two categories in our chapter because of two reasons. First, what we present in our own work relates to the eight categories listed above, and these two categories seem to be less used in educational games. Second, we believe that these two categories can be addressed in the other eight categories. For example, feedback and cues can be personalized.

The first type of support is *reflection*. This group of supports aims to stimulate learners' thinking about their performance and learning in the game. Research has shown that knowledge retention is improved if students are required to reflect on what they learned (e.g., Leemkuil, 2006). Some of the learning supports in games categorized under reflection include: (1) self-explanation (asking learners to explain to themselves—verbally or written—as they study a lesson/concept; Johnson & Mayer, 2010), (2) elaboration (extra task-related cognitive activities; Shebilske, Goett, Corrington, & Day, 1999), and (3) assignments (e.g., queries to find relationships between two or more variables; Leemkuil, 2006). These types of support can be implemented in various forms during gameplay (e.g., reflective questions, extra cognitive tasks, reviewing and discussing their answers/solutions). The point is that this group of supports help learners pause for a moment, analyze their answers/solutions, and use organizational and integrational cognitive processes to learn the underlying concepts within the game.

The second type of support is *modeling*. This group of supports provides an explication or illustration of how to solve a problem or perform a task in the game. The two most common supports categorized under the modeling category are: (1) scaffolding (Barzilai & Blau, 2014), and (2) worked examples (or expert solutions; Lang & O'Neil, 2008). Modeling can be provided either inside or outside of the game, by a peer, expert, or the game itself; and it can be delivered verbally, graphically, or via animated form. One possible criticism regarding the inclusion of worked examples in a game is that learners can see a solution and then replicate it without actually thinking about the underlying concepts being used to solve the problem. However, with a good reward/penalty system in place, negative effects of using worked examples can be minimized. Also, providing partially worked examples can reduce the potential negative effect of fully worked examples. This is described in more detail in Sect. 3 where we present an example of integrating such worked examples in our game called *Physics Playground*.

The third type of support is *advice* (e.g., Leutner, 1993), intended to guide the learner in the right direction without revealing the solution. All types of advice (contextualized, adaptive or not) that are game-generated can be grouped under this category. For example, a hint can provide the learner with suggestions about what to do next in the game, or provide an elaborated explanation about possible consequences of his/her action. Advice can consist of a short message asking the player to focus on a particular aspect of the task, or give a cue about where to start.

The fourth support category is *collaboration* (van der Meij, Albers, & Leemkuil, 2011), which may involve other players discussing the game or a particular level. Collaboration can help novice players figure out ambiguities in the game and better understand the knowledge and skills they need to learn. Many games allow for live chat and exchange of information among players. Alternatively, collaborative gameplay may be done with learners playing the game in dyads or small groups, and then they can get involved in after-game discussions in online forums or in physical environments (e.g., a classroom).

The fifth learning support type is *interactivity*. This category is more focused on giving choices and control to the learners. Any type of learning support which is responsive to learners' actions can be categorized under this group. For example, Moreno and Mayer (2005) designed their agent-based multimedia game with interactivity where students, for example, had to select roots, stems, and leaves that best helped plants survive on the planet. Another group of students used a different version of the game (i.e., with no interactivity). They interacted with a pedagogical agent who simply showed them pertinent information regarding the plants. The authors found that interactivity helped students learn and retain knowledge more than non-interactivity.

Narrative elements comprise the sixth type of learning support, where content can be integrated into the storyline of a game via narratives that contain surprises, foreshadowing, and fantasies. The narrative of a game provides a cognitive framework for the learners with which they can better learn and remember the underlying concepts in the game (e.g., Adams, Mayer, MacNamara, Koenig, & Wainess, 2012).

This type of support can be seen, as Prensky (2001) pointed out, in genres such as adventure games or role-playing games.

The seventh type of learning support—and likely the most powerful one—is *feedback*, especially formative feedback which is essential for learning (Shute, 2008). Given the high degree of interactivity existing in most games, feedback becomes critically important. As Shute (2008) notes, there are many types of feedback, but the two most common types used in educational games are corrective feedback (e.g., showing if an answer/solution is correct or not), and explanatory feedback (e.g., describing why the answer/solution was right or wrong). Cameron and Dwyer (2005) found statistically significant differences on all learning outcomes when feedback was included in the game versus when it was not.

Finally, the eighth support category is *modality* (Ginns, 2005; Moreno & Mayer, 2002; Ritterfeld, Shen, Wang, Nocera, & Wong, 2009). That is, learning supports can be provided via different modalities (i.e., auditory, visual, textual) and each type can positively or negatively affect learning. For example, Moreno and Mayer (2002) found that learners remembered more of the materials, achieved better transfer, and rated more favorably virtual reality environments that used speech rather than on-screen text to deliver learning materials. Also, Ritterfeld and colleagues (2009) point out that multimodality is one of the most important aspects of educational game success—providing learners with materials via different channels. Results of their study showed that multimodality positively affects knowledge gains for both short-term (at the posttest) and long-term (follow-up test) outcomes.

The foregoing learning supports can be personalized and adaptive to learners. That is, the what, the where, the how, and the when of learning supports can be tailored to the current needs of the learners as well as preferences. After conducting a moderator analysis, Wouters and van Oostendorp (2013) found out that among the 29 studies they examined, reflection, modeling, collaboration, modality, and feedback enhanced learning, but advice, interactivity, and narrative did not. This does not mean that the non-significant learning supports types will never be useful; rather, the effectiveness of all learning supports is likely dependent on appropriately integrate learning supports into educational games. In the next section, we present an example of designing, developing, and implementing learning supports in a specific educational game.

3 Learning Supports in Physics Playground

As mentioned earlier, different types of learning supports tend to promote learning across educational games (Wouters & van Oostendorp, 2013). However, details about particular features and their associated effectiveness of different types of learning supports are lacking in the literature (Johnson, Bailey, & Van Buskirk, 2017; Ke, 2016). Ke and Shute (2015) pointed out that next generation of educational games will likely embody two related functions: (1) game-based stealth assessment, and (2) adaptive learning supports, which are based on the results of the in-game assessment. Effectively integrating the assessment and associated supports must rely on an iterative game design process.

In this section, we describe some of our processes related to developing, implementing, and testing various learning supports in the game *Physics Playground* (Shute & Ventura, 2013).

3.1 Original Version of Physics Playground

Physics Playground (PP) is a homemade 2D physics game designed to enhance qualitative physics understanding. In the original version of *PP*, we used stealth assessment technology (Shute, 2011) to measure player's conceptual understanding of physics related to: (1) Newton's laws of force and motion, (2) potential and kinetic energy, and (3) conservation of angular momentum (Shute, Ventura, Kim, & Wang, 2014).

The nonlinear version of *PP* had only one game type—the sketching interface. The sketching levels require players to draw simple machines (i.e., lever, ramp, pendulum, and springboard) to guide a green ball to hit a red balloon—the goal in all levels. Players can win a silver or gold trophy for solving a level, but no trophies for failures. Crafting optimal solutions get them a gold trophy. In the *Chocolate Factory* level (see Fig. 1), players who solve it within two steps get a gold trophy (i.e., drag

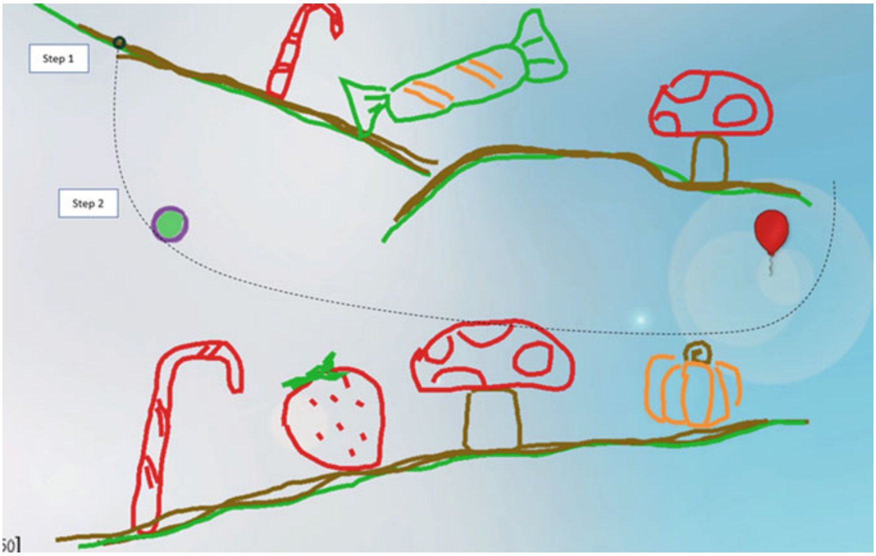


Fig. 1 *Chocolate Factory* level in *Physics Playground*

a pin to the tree branch (Step 1), draw a ramp from the pin following the path of the dotted line (Step 2), then the ball will travel along the ramp and hit the balloon).

Over the past decade, we have conducted various empirical studies testing the effectiveness of *PP* on a range of competencies including physics understanding and other competencies, such as creativity and persistence. We consistently found that (1) *PP* can foster motivation and learning, and (2) the embedded stealth assessment measures are reliable and valid—significantly correlated with external measures (see Shute et al., 2015). The goal, however, was to enhance the game by including targeted in-game learning supports. This led to new funding (NSF and IES) to design, develop, and test both cognitive and affective *stealth-assessment-based adaptive learning supports* (with our focus in this chapter on the cognitive supports). Over the course of the past 2 years, we conducted several usability studies to design a new version of *PP*. In the following sections, we first discuss the challenges we faced and decisions we made along the way. Then, we will elaborate on the current version of *PP*.

4 Challenges We Faced, and Decisions We Made

Well-designed games and good instructional design should go hand-in-hand (Hirumi, Appelman, Rieber, & Van Eck, 2010; Shute, Rieber, & Van Eck, 2011). But introducing learning supports in a game poses two main challenges: (1) providing appropriate support without giving away the answers (e.g., Hirumi et al., 2010), and (2) ensuring alignment between learning supports and game mechanics (i.e., game rules) without disrupting the flow (Ke & Shute, 2015), particularly since the effectiveness of the supports vary depending on the degree of cognitive load and game flow (Ke, 2016).

This section focuses on the specific hurdles we encountered and our decisions to surmount them during the development of the cognitive supports that align with game mechanics in *PP*. We describe how we sought the sweet spot between the land of theory (learning supports) and the land of data (results of several usability studies).

4.1 Early Version of Learning Supports

We adopted the physics competency model to undergird the systematic design iterations of the supports in *PP*. The early version of the cognitive supports included five different types of support (Fig. 2): (1) Game tutorial, (2) Worked examples, (3) Hewitt videos, (4) Physics facts, and (5) Advice.

Game tutorials resided in two separate playgrounds. The sketching tutorial playground consisted of six interactive tutorials (i.e., game mechanics, nudge, ramp, lever, pendulum, and springboard). The manipulation tutorials introduced essential game tools relevant to our new task type we developed (i.e., blower and puffer, general sliders, specific sliders, and bounciness).

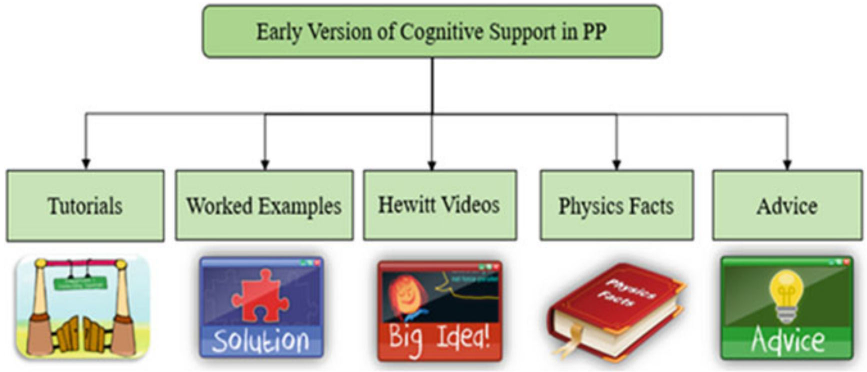


Fig. 2 First version of cognitive support in *Physics Playground*

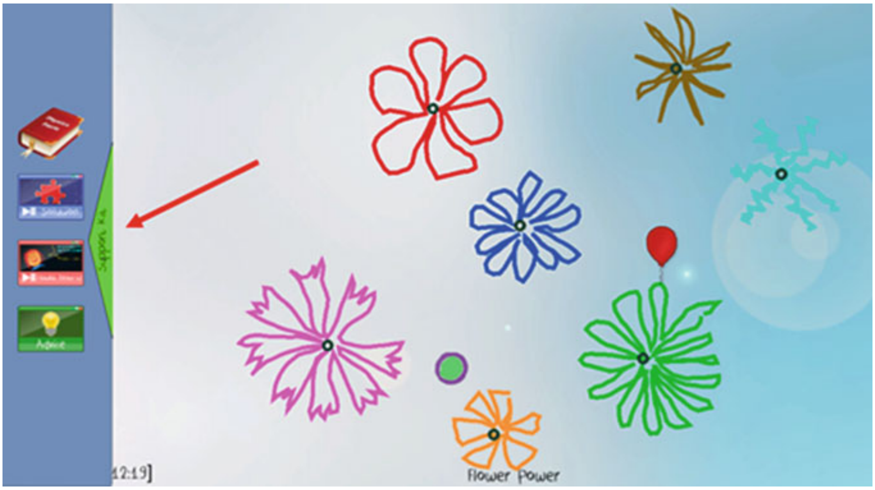


Fig. 3 Support menu in *Flower Power* level in *Physics Playground*

In addition to the tutorials, students could access other supports in a level via the "support kit" tab located at the left-hand side of screen. Clicking on the tab opened the support menu (Fig. 3). This allowed students to access physics facts, worked examples, and Hewitt videos if they were in a level playing for less than 5 min. The advice icon only appeared when the game detected a student was at the same level ≥5 min.

Clicking on the Physics facts support (i.e., the dictionary icon) led to a non-interactive list showing all the relevant terms, definitions, and short examples. Clicking on the Worked Example support (i.e., the jigsaw puzzle icon) directed students to the solution video. Clicking on the Hewitt video support allowed students to watch a physics video explaining the primary concept related to the level. And clicking on

Advice (i.e., the light bulb icon) triggered a short, general hint for solving a level (e.g., “Remember that a larger force will cause an object to accelerate faster”).

4.2 Usability Study 1

To examine the effects of the five cognitive supports and our new task type (e.g., manipulation levels), we conducted the first usability study at our laboratory school, Florida State University School (FSUS) at the end of the first year of the project. FSUS is located in Tallahassee, Florida, in an urban/suburban setting. It is a K-12 school whose heterogeneous student population represents Florida’s population demographics (50% white, 29% African-American, 12% Hispanic, 5% Multicultural, 3% Asian, and 0.2% Native American). In FSUS, 21% of middle school students and 11% of high school students are enrolled in the free and reduced lunch program. Recruitment occurred via science teachers in their classes, and flyers at the school.

In the 3-day study, we observed and interviewed 24 9th to 11th grade students, who were either paired or played individually for a total of 150 min. On day 3, the students completed an 18-item physics test (developed by our physics experts as well as our measurement experts). All gameplay and test data were captured in log files. We developed a think-aloud protocol detailing the researcher-initiated prompts on the supports, game features, new tasks and levels, and test items. We also recorded students’ additional comments on the game and technical glitches that occurred during gameplay. Such data triangulation allowed for a deep look at what really worked and what did not and gave direction on the next design phase.

We hypothesized that the five supports would be somewhat effective in developing physics understanding (as measured by the physics test). However, the study yielded mixed results—i.e., game tutorials were viewed as generally helpful, and the new manipulation task types were well-received. However, while students clearly favored the worked examples and Hewitt videos, they had mixed (mostly negative) feelings toward the Physics facts and Advice. The data showed that while the worked examples were the most frequently accessed support, the other supports were rarely used. This led us to redesign the learning supports based on five main decisions.

- *Redesign the Support Kit Tab*: None of the students opened the tab voluntarily—we decided to revise the color and position of the tab to make it clear and visually appealing.
- *Revise the Tutorials*: While most students reported the tutorials were straightforward and clear, some had a hard time creating optimal simple machine(s) per level. Consequently, we created and inserted agent-specific tutorials in the support kit tab to remind students to review each when needed.
- *Redesign Physics Facts*: Not surprisingly, the majority of students noted that the Physics Facts support was boring. We decided to change the static definitions to a matching game for the terms. In short, they now, interactively, construct their definitions of terms, like a Cloze task (Taylor, 1953).

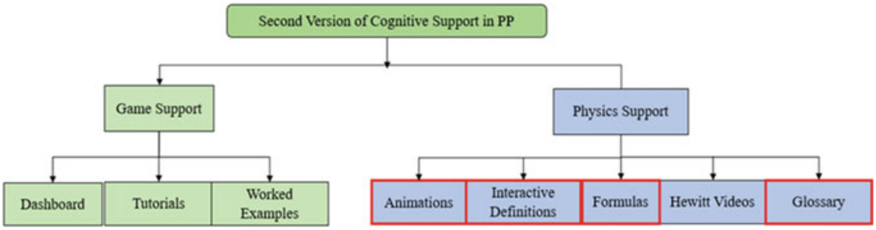


Fig. 4 Second version of supports in *Physics Playground*

- *Design Reward System*: Moreover, a number of students mentioned that they would watch the Hewitt Videos, etc., if incentives were provided. This motivated our design of a reward system for the game.
- *Remove Advice*: Students felt that the Advice support was neither specific nor helpful. We decided to remove Advice and design more level-specific physics hints.

After several rounds of discussion and revision, we further refined our supports and came up with the second version of learning supports as shown in Fig. 4. The new supports are highlighted in red.

In the second version, we made the following changes:

- *New help system*: We regrouped the supports into physics-related and game-related categories. We converted the Physics Facts support to a simpler Glossary. And as mentioned, we added animations, interactive definitions, and formula options to provide additional support for the growth of formal physics knowledge. We also replaced the support kit tab with a simpler Help button. Thus, the new support system provides three types of help: “Show me the Physics,” “Show me a Solution or Hint,” and “Show me Game Tips” (see Fig. 13).
- *Dashboard*: We created a dashboard (Fig. 5)—accessible from the main menu in the game—and called it “My Backpack.” My Backpack displays the player’s progress regarding estimates of current physics knowledge, the number of levels completed and remaining, money earned, and a store offering customizable items (i.e., changing ball type and color, changing music, and changing the background image).
- *Reward system*: Research shows that game incentive structures and level progression are core aspects of game rule design (Ke, 2016). The game allows students to earn gold/silver coins when they solve a level or access the supports/game tutorials. The back of both coins shows the head of Sir Isaac Newton. One gold coin = \$20, while one silver coin = \$10. We employed dollars (\$) as the game currency for familiarity. The coins earned will be automatically converted to dollars and appear in the money bag located on the dashboard.

We conducted the second usability study to test the effectiveness of the second version of our learning supports.

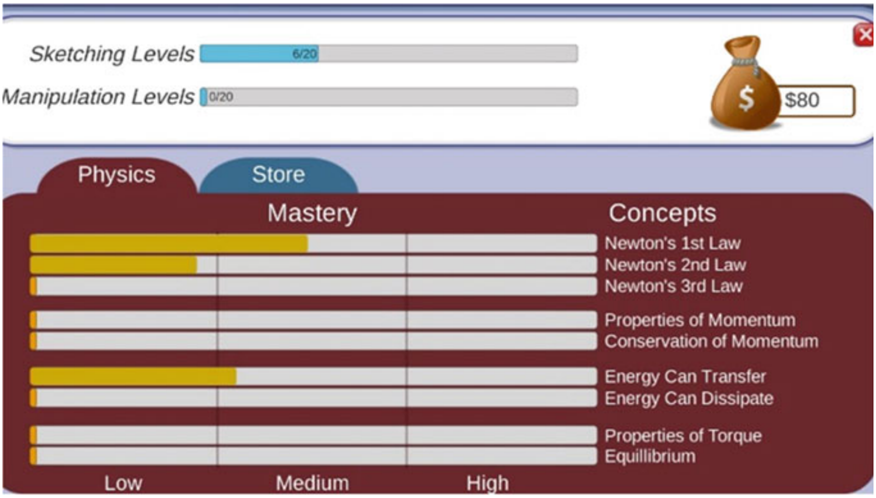


Fig. 5 Dashboard in *Physics Playground* (My Backpack)

4.3 Usability Study 2

In the second usability study, we observed the gameplay of 44 8th grade students at the same school in Usability Study 1 across three days, with a posttest and a questionnaire on day four. The students were assigned to two groups: learning support and non-learning support. Both groups played about 40 min each day.

Despite some technical issues, the results showed that students were quite excited and engaged when playing the game. They did note that the tutorials were too long and not interactive, which echoed the comments obtained from the first usability study. Also, like the first usability study, the learning support most accessed by this group accessed was "Show me a Solution" (i.e., worked examples). Again, the other supports were not often used. This reinforced the need for a good reward system operational in the game—to limit the abuse of worked examples, and to direct more attention to the other supports intended to engender physics understanding.

These results motivated us to make the following decisions: (a) revise and operationalize the reward system with a reasonable incentive scheme intended to increase students' motivation to view various physics supports (e.g., we raised the price of a worked example from \$30 to \$60, changing the cost of a background image from \$5 to \$20, changing music from \$15 to \$40, and changing ball color from \$30 to \$60), (b) add a free hint to the "Show me a Solution" tab, and (c) create interactive tutorials for both sketching and manipulation levels (see Sect. 4). The current supports are shown in Fig. 6.

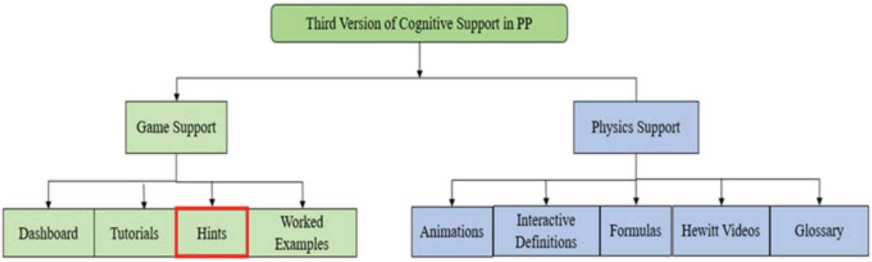


Fig. 6 Third version of supports in *Physics Playground*

4.4 Usability Study 3

Before conducting the third usability study, after looking at what we found from the first two studies, we developed a set of new learning supports, and a new set of test items (i.e., near-transfer items). The purpose of usability study 3 was to (1) investigate the effectiveness of the *new learning supports* accessible via the Help button (i.e., seven animations explaining the energy can transfer [ECT] and properties of torque [POT] concepts with narrations; see Fig. 7) when combined with game play, and (2) pilot-test our *near-transfer* test items we developed (Fig. 8). For these purposes, we selected the two minimally overlapping concepts in our competency model: ECT and POT. We also developed a new set of tutorials for nudge, lever, ramp, pendulum, and springboard. In total, students had 35 levels to complete.

To evaluate students' physics understanding, we used two physics test forms (Form A = 14 items; Form B = 14 items), each of which included 10 near-transfer test items (i.e., less technical, and more similar to the *PP* levels), and 4 far-transfer test items (i.e., similar to the Force Concept Inventory test items; see Fig. 9). Also,

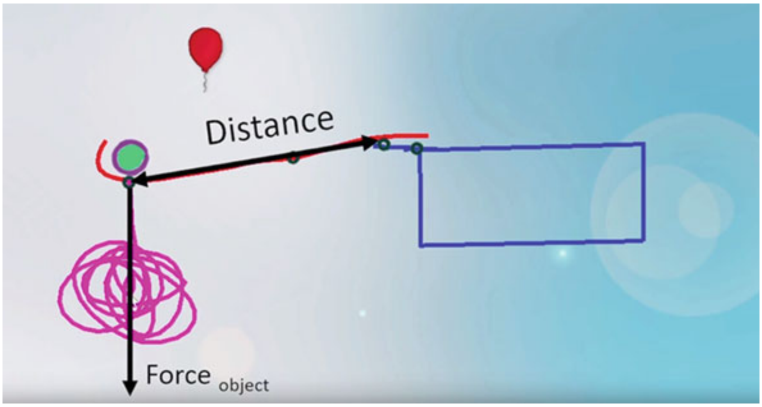
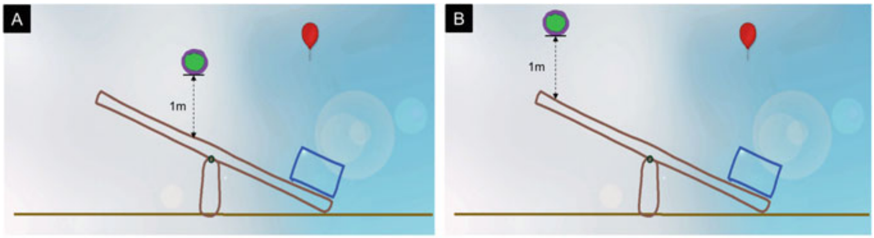


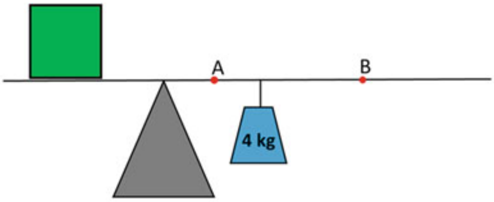
Fig. 7 One of the new learning supports (see the video here: https://bit.ly/2HymeoA)



In which picture (A or B) will the blue box bounce higher?

a) A
b) B
c) Both will reach the same height.
d) Not enough information

Fig. 8 An example of our POT near-transfer test items. The answer is B



If the lever is balanced in the picture above, which of the following would cause the lever to go unbalanced?

a) Replace 4 kg with 8 kg and move it to point A
b) Replace 4 kg with 8 kg and move it to point B
c) Both
d) Neither

Fig. 9 An example of our POT far-transfer test items. The answer is B

to evaluate students' game satisfaction and learning supports satisfaction, we used a 16-item, Likert-scale questionnaire.

Our convenience sample included 14 students (6 seventh graders, 8 eighth graders; 6 female, 8 male) from a school of arts and sciences at Florida who were compensated with a $10 gift card upon the completion of the study. Students first completed a demographic questionnaire followed by the pretest in about 20 min. Then, all the students played the game for 75 min in two stages: (1) the first 20 min: getting familiar with the game through the tutorials and freely accessing all the learning supports, and (2) the next 45 min: playing the game with accessing only the "physics supports" (in this stage the researchers prompted the students to access the "physics supports" after playing 3 levels or every 8 min). At the end of the gameplay, students completed the posttest, and the game and learning supports satisfaction questionnaire (all the tests were administered online using Qualtrics).

Results showed a Cronbach's α of 0.61 for our ECT and 0.38 for our POT near-transfer items (both pre and posttest items included; the problematic items have been identified and revised for future use). Students scored significantly higher on the posttest compared to the pretest ($M_{pre} = 0.57$, $M_{post} = 0.63$, $t\ (13) = -2.20$, $p < 0.05$, Cohen's $d = 0.60$), suggesting learning occurred. Also, the near-transfer pretest significantly correlated with the near-transfer posttest ($r = 0.53$, $p < 0.05$), suggesting reliability.

Finally, the analysis of students' overall game and learning supports satisfaction showed that students really enjoyed playing the game ($M = 4.24$, $SD = 0.62$, where $1 =$ strongly disagree and $5 =$ strongly agree), and they saw the learning supports as useful and easy to use ($M = 3.99$, $SD = 0.51$). Moreover, males and females equally enjoyed the game. These findings have convinced us that we are on the right path. We plan to conduct a more rigorous study in the near future to examine the effectiveness of our new supports, and ultimately select the supports that are most effective. Next, we describe the current version of the game.

5 Current Version of PP

As explained in Sect. 4, over the past 2 years, we have been designing and testing the effectiveness of a variety of learning supports in *PP* to foster deep, more formal understanding of Newtonian physics. We are finalizing the cognitive supports and working towards developing an adaptive stealth assessment-based level selection algorithm. To get to the current version of the game that was used in our usability studies, we started by establishing a new, broader physics competency model, compared to the sparse model used in the past.

5.1 New Competency Model

Using the Next Generation Science Standards (NGSS) as our guidepost, we worked with our two physics experts to select primary physics competencies and sub-competencies to be assessed in the new version of *PP*. We also identified all salient game behaviors (or "indicators") that can provide evidence of the proficiency status of each variable in the competency model. After many revisions, we finally came up with the competency model shown in Fig. 10. The model involves four primary competencies: force and motion, linear momentum, energy, and torque. The model serves as the foundation for subsequent design phases (e.g., designing and developing a new task type).

Fig. 10 Competency model for *Physics Playground*

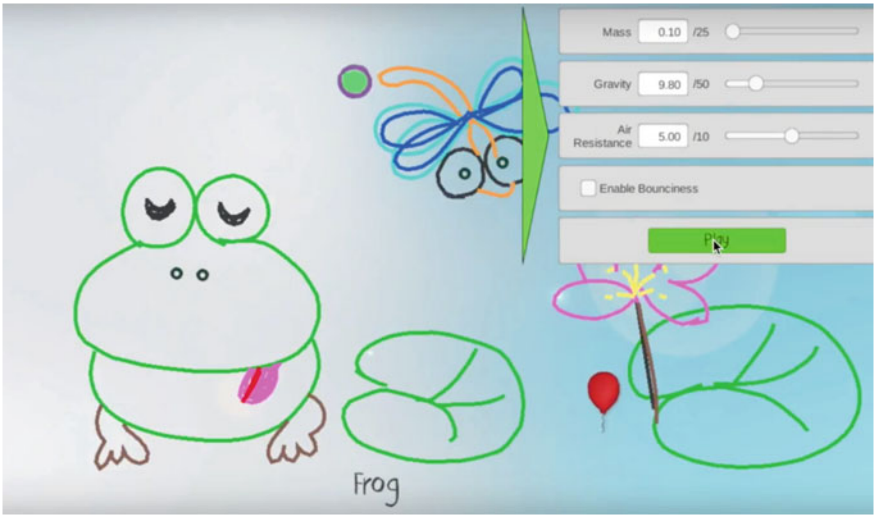
5.2 New Task Type and Levels

Given this expanded competency model, we needed task types that could elicit evidence of the new physics concepts. This resulted in the design of our new manipulation task type, with drawing functionality disabled. Manipulation tasks require players to adjust three sliders (i.e., gravity, mass, and air resistance), a bounciness option, and add external forces as needed (i.e., static and dynamic blowers, as well as puffers) to solve a level. For instance, solving the *Frog* level (see Fig. 11) requires players to adjust air resistance and enable the bounciness function.

5.3 Specific Learning Supports

Across the past 2 years, we developed 8 different learning supports for the game: (1) worked examples, (2) animations, (3) interactive definitions, (4) formulas, (5) Hewitt videos, (6) glossary, (7) hints, (8) new physics supports (as we called the new learning supports in Sect. 3), and (9) interactive tutorials.

In line with Wouters and van Oostendorp's (2013) categorization summarized in Sect. 2, our worked examples (i.e., short videos showing expert solutions per level) relate to Modeling; our hints relate to Advice; and our animations, formulas, Hewitt videos, and glossary relate to Modality in that each physics concept in the game



Mass 0.10 /25

Gravity 9.80 /50

Air Resistance 5.00 /10

☐ Enable Bounciness

Fig. 11 *Frog* Level in *Physics Playground*

can be presented across multiple representations of the targeted physics knowledge. We selected Modeling, Modality, and Hints as the main types of support to include in the game because Modeling and Modality appear to be the most effective supports to elevate student learning relative to other learning supports (Wouters & van Oostendorp, 2013).

To access the supports while playing a level, students click the help button (see left panel of Fig. 12) in the lower-right corner of the screen (note: currently accessing supports is controlled by the player but in upcoming studies, we will examine the effects of player- versus game-control of the supports). This triggers a pop-up window showing three options: “Show me the Physics,” “Show me a Solution or a Hint,” and “Show me Game Tips” (see right panel of Fig. 12). “Show me the Physics” comprises the main learning support—where students can learn about physics phenomena via multiple representations (i.e., physics animations with narration, interactive definitions, formulas, Hewitt videos, and a glossary). “Show me a Solution or a Hint” and “Show me Game Tips” focus on game-related support—where students can access tutorials, view reminders about game mechanics, and learn about “My Backpack,” the latter depicting their current progress and allowing them to customize the game environment.

Show me the Physics leads the student to the physics page showing the following options: “Animation,” “Definition,” “Formula,” “Hewitt video,” and “Glossary” (see Fig. 13; note that the formula is not present if the concept doesn’t have an associated formula or equation).

- *Physics animations*. The new physics animations, with narration, connect the physics concepts with how they are applied in the game to solve a level (see Fig. 7

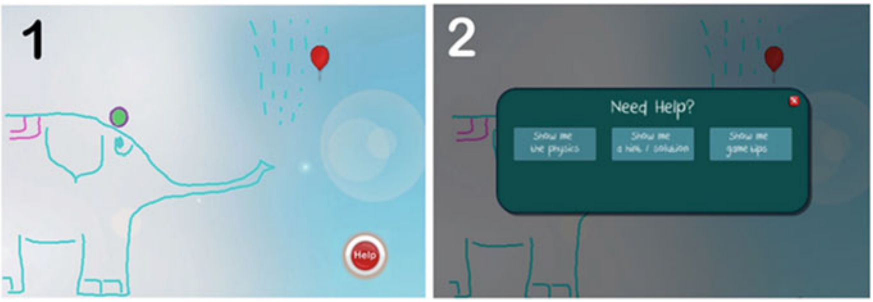
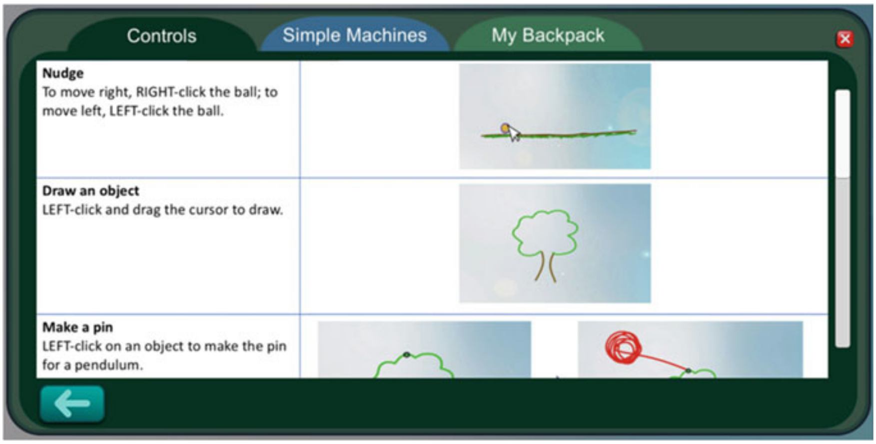


Fig. 12 “Help” button and help menu after the “Help” button is clicked

Fig. 13 “*Show me the Physics*” menu

for an example). These videos follow the same structure: (1) introduce the concept that will be presented in the video (e.g., “Here you are going to see how energy is transferred to a ball using a pendulum”), (2) state the concept (e.g., “gravitational potential energy is the energy of height…”), (3) demonstrate a failed attempt to solve a level in PP environment (i.e., the pendulum does not have enough angular height), and then (4) show a successful attempt to solve that level.

- *Interactive Definitions*. An interactive task that allows students to drag and drop the choices to the right place and complete a definition of a physics term. In the upper left is the animation related to the term. Students watch the animation and drag the five phrases to the correct blanks within the definition. When the blanks are correctly filled, a congratulation message pops up and students see the complete definition of the term.
- *Formulas*. Not all terms have associated formulas or formulas appropriate for the student level. Clicking on a formula card reveals the formula, along with a short explanation of each component/variable.



Nudge
To move right, RIGHT-click the ball; to move left, LEFT-click the ball.

Draw an object
LEFT-click and drag the cursor to draw.

Make a pin
LEFT-click on an object to make the pin for a pendulum.

Fig. 14 "*Show me Game Tips*" menu

- *Hewitt Videos*. Hewitt videos are an engaging series of cartoon videos explaining various physics concepts, developed by Paul Hewitt. The team edited the length of each video to make it illustrate one targeted competency only (we received Paul Hewitt's permission to edit and use the videos).
- *Glossary*. The glossary provides brief explanations of 28 physics terms. The terms have been selected, edited, and revised by the physics experts. Each level is linked to only one physics term. However, students can access the glossary at any time.
- Clicking on *Show me a Solution or a Hint* (Fig. 13) opens a pop-up window. Based on feedback from two usability studies, we designed hints to help those who are struggling but are reluctant to watch the solutions. For instance, if a sketching level can only be solved by a springboard, the free level-specific hint will be: "Try drawing a springboard." If a student elects to view a worked example, he or she will watch a worked example after paying $60 as a disincentive. All worked examples are 1–2 min long. The worked examples are complete and can be viewed here on our YouTube channel.

Finally, *Show me Game Tips* (Fig. 14) is where students can find game rules, review game tutorial images, and learn about "My Backpack." Clicking on the button leads to a page containing 2–3 tabs. "Controls," "Simple Machines," and "My Backpack" tabs are for sketching tasks, and "Tools" and "My Backpack" are for manipulation.

- *"Controls" and "Simple Machines."* When a student clicks on the "Controls" tab, a scrollable page pops up showing game mechanics (i.e., nudge, draw an object, and delete an object for a sketching level). When a student clicks on the "Simple Machines" tab, four annotated images of the four simple machines (i.e., lever, pendulum, ramp, and springboard) show up. Each image is clickable and can be enlarged. Viewing the Simple Machines' images the learners can quickly remember how the agents work and they don’t have to go through the full tutorials again.

- *Tools*. Clicking on “Show me Game Tips” when the player is in a manipulation level, provides rules for the sliders in manipulation tasks and a short explanation about other tools available (i.e., puffers and blowers).
- *My Backpack*. In both sketching and manipulation levels, “Show me Game Tips” includes “My Backpack.” A screenshot from “My Backpack” will be shown with textboxes pointing at different parts of “My Backpack” explaining its function.
- *Game Tutorials*. The tutorials are interactive levels with on-screen instructions. Sketching tutorials show how to draw simple machines. Manipulation tutorials show how to use the puffer/blower (that can exert a one-time and small force or a constant force), sliders (i.e., for mass, gravity, and air resistance), and bounciness function. Students can access them either from the playgrounds or their static images in “*Show me Game Tips*” button.

We will make a decision, based on all the usability study results, about the best learning supports to include in the final version of the game.

6 Conclusion and Future Research

In this chapter, we presented findings related to the effectiveness of educational games, specifically concerning those with embedded learning supports, and discussed various types of learning supports identified in the literature. Additionally, we illustrated how we designed, developed, and tested different learning supports in our educational game—*Physics Playground*. Although the literature is divided about supporting learning in various learning environments (especially exploratory environments), we concluded that having learning supports in educational games can have a positive impact on learning. Among the types of learning supports identified by Wouters and van Oostendorp (2013), reflection, modeling, collaboration, modality, and feedback have been found to consistently enhance learning.

We detailed our efforts in designing and integrating learning supports in the game *Physics Playground*, and determined which supports worked best to foster learning. Our three usability studies yielded mixed results in response to this question, showing that while a large majority of students indeed enjoyed the game, the modeling learning supports (i.e., worked examples) were viewed as the most helpful compared to advice (i.e., hints) and modality (i.e., old animations, formulas, Hewitt videos, and glossary—the multiple representations we developed per relevant physics concept). We also found that our new physics animations are effective and we are currently creating the rest of the videos for all the concepts. Moreover, we found that in the previous versions of the game, students were not adequately motivated to access the other more helpful learning supports (e.g., physics-related supports), given the absence of an appropriate in-game reward system. Therefore, we are currently revising the game and supports to (a) further clarify and enhance the appearance and interactivity of the learning supports, (b) provide easier, more direct access to the supports, and (c) set up a compelling and functional reward system.

Moving forward, there are a number of potential avenues for research in this area, such as determining the degree to which a reward system actually influences students' play experience and motivation to access learning supports in the game. Towards that end, we are (1) optimizing the cognitive supports and the game reward system; (2) developing affective supports to complement the cognitive supports that we have developed (not focused on in this chapter); and (3) using stealth assessment technology to serve as the basis for an in-game adaptive algorithm that will select the best next level for a person—one that is not too difficult nor too easy and related to the targeted physics concept.

This sampler of ongoing research will help us and the field figure out ways to optimize the design and delivery of learning supports that may be unobtrusively incorporated into games. The process should be iterative and provide research-backed evidence on: (1) the effects of different types of cognitive and affective supports that promote formal learning and enjoyment in educational games; (2) the timing and control of such supports (e.g., when should they be available, and who—computer or player—controls the delivery; and (3) the factors that mediate the influence of supports on learning and gameplay.

Acknowledgements We wish to express our gratitude to the funding by the US National Science Foundation (NSF #037988) and the US Department of Education (IES #039019) for generously supporting this research.

References

Adams, D. M., Mayer, R. E., MacNamara, A., Koenig, A., & Wainess, R. (2012). Narrative games for learning: Testing the discovery and narrative hypotheses. *Journal of Educational Psychology, 104*(1), 235.

Barab, S., Thomas, M., Dodge, T., Carteaux, R., & Tuzun, H. (2005). Making learning fun: Quest Atlantis, a game without guns. *Educational Technology Research and Development, 53*(1), 86–107.

Barzilai, S., & Blau, I. (2014). Scaffolding game-based learning: Impact on learning achievements, perceived learning, and game experiences. *Computers & Education, 70,* 65–79.

Black, A. E., & Deci, E. L. (2000). The effects of instructors' autonomy support and students' autonomous motivation on learning organic chemistry: A self-determination theory perspective. *Science Education, 84*(6), 740–756.

Bruffee, K. A. (1993). *Collaborative learning: Higher education, interdependence, and the authority of knowledge*. Baltimore, MD: Johns Hopkins University Press.

Cameron, B., & Dwyer, F. (2005). The effect of online gaming, cognition and feedback type in facilitating delayed achievement of different learning objectives. *Journal of Interactive Learning Research, 16*(3), 243–258.

Clark, D. B., Tanner-Smith, E. E., & Killingsworth, S. S. (2016). Digital games, design, and learning: A systematic review and meta-analysis. *Review of Educational Research, 86*(1), 79–122.

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. New York: Harper and Row.

de Castell, S., & Jenson, J. (2003). Serious play: Curriculum for a post-talk era. *Journal of the Canadian Association for Curriculum Studies, 1*(1), 47–52.

Entertainment Software Association. (2016). *2016 Essential facts about the computer and video game industry*. Retrieved from http://essentialfacts.theesa.com/Essential-Facts-2016.pdf.

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. https://doi.org/10.1016/j.chb.2010.10.026.

Gee, J. P. (2003). What video games have to teach us about learning and literacy. *Computers in Entertainment (CIE), 1*(1), 20–20.

Gee, J. P. (2008). Learning theory, video games, and popular culture. In *The international handbook of children, media, and culture* (pp. 196–211).

Ginns, P. (2005). Meta-analysis of the modality effect. *Learning and Instruction, 15*(4), 313–331.

Granic, I., Lobel, A., & Engels, R. C. (2014). The benefits of playing video games. *American Psychologist, 69*(1), 66.

Green, C. S., & Bavelier, D. (2007). Action-video-game experience alters the spatial resolution of vision. *Psychological Science, 18*(1), 88–94.

Green, C. S., & Bavelier, D. (2012). Learning, attentional control, and action video games. *Current Biology, 22*(6), R197–R206. https://doi.org/10.1016/j.cub.2012.02.012.

Hirumi, A., Appelman, B., Rieber, L., & Van Eck, R. (2010). Preparing instructional designers for game-based learning: Part 1. *TechTrends, 54,* 27–37.

Johnson, C., Bailey, S., & Van Buskirk, W. (2017). Designing effective feedback messages in serious games and simulations: A research review. In P. Wouters & H. van Oostendorp (Eds.), *Instructional techniques to facilitate learning and motivation of serious games* (pp. 119–140). New York, NY: Springer.

Johnson, C. I., & Mayer, R. E. (2010). Applying the self-explanation principle to multimedia learning in a computer-based game-like environment. *Computers in Human Behavior, 26*(6), 1246–1252.

Kamarainen, A. M., Metcalf, S., Grotzer, T., Browne, A., Mazzuca, D., Tutwiler, M. S., & Dede, C. (2013). EcoMOBILE: Integrating augmented reality and probeware with environmental education field trips. *Computers & Education*, *68*, 545–556.

Ke, F. (2008). Alternative goal structures for computer game-based learning. *International Journal of Computer-Supported Collaborative Learning, 3*(4), 429.

Ke, F. (2013). Computer-game-based tutoring of mathematics. *Computers & Education, 60*(1), 448–457.

Ke, F. (2016). Designing and integrating purposeful learning in game play: A systematic review. *Educational Technology Research and Development, 64*(2), 219–244.

Ke, F. F., & Shute, V. J. (2015). Design of game-based stealth assessment and learning support. In C. Loh, Y. Sheng, & D. Ifenthaler (Eds.), *Serious games analytics* (pp. 301–318). New York, NY: Springer.

Kim, Y. J., & Shute, V. J. (2015). The interplay of game elements with psychometric qualities, learning, and enjoyment in game based assessment. *Computers & Education, 87,* 340–356.

Lang, J., & O'Neil, H. (2008). *The effect of presenting just-in-time worked examples for problem solving in a computer game*. Paper presented at the American Educational Research Association, New York, US.

Laurel, B. (2001). *Utopian entrepreneur*. Cambridge, MA: MIT Press.

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

Leemkuil, H. H. (2006). *Is it all in the game? Learner support in an educational knowledge management simulation game.* Unpublished doctoral dissertation, Universiteit Twente, The Netherlands.

Leemkuil, H., & de Hoog, R. (2005). Is support really necessary within educational games? In C. Conati & S. Ramachandran (Eds.), *Educational games as intelligent learning environments* (pp. 21–31). Amsterdam, The Netherlands.

Leutner, D. (1993). Guided discovery learning with computer-based simulation games: Effects of adaptive and non-adaptive instructional support. *Learning and Instruction, 3*(2), 113–132.

Moreno, R., & Mayer, R. E. (2002). Learning science in virtual reality multimedia environments: Role of methods and media. *Journal of Educational Psychology, 94*(3), 598.

Moreno, R., & Mayer, R. E. (2005). Role of guidance, reflection, and interactivity in an agent-based multimedia game. *Journal of Educational Psychology, 97*(1), 117.

Prensky, M. (2001). Digital natives, digital immigrants part 1. *On the horizon, 9*(5), 1–6.

Ritterfeld, U., Shen, C., Wang, H., Nocera, L., & Wong, W. L. (2009). Multimodality and interactivity: Connecting properties of serious games with educational outcomes. *Cyberpsychology & Behavior, 12*(6), 691–697.

Shebilske, W. L., Goettl, B. P., Corrington, K., & Day, E. A. (1999). Interlesson spacing and task-related processing during complex skill acquisition. *Journal of Experimental Psychology: Applied, 5*(4), 413.

Shute, V. J. (2008). Focus on formative feedback. *Review of Educational Research, 78*(1), 153–189.

Shute, V. J. (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 Publishers.

Shute, V. J., D'Mello, S. K., Baker, R., Cho, K., Bosch, N., Ocumpaugh, J., …, & Almeda, V. (2015). Modeling how incoming knowledge, persistence, affective states, and in-game progress influence student learning from an educational game. *Computers & Education, 86*, 224-235.

Shute, V. J., & Ke, F. (2012). Games, learning, and assessment. In *Assessment in game-based learning* (pp. 43–58). New York, NY: Springer.

Shute, V. J., Rieber, L., & Van Eck, R. (2011). Games … and … learning. In R. Reiser & J. Dempsey (Eds.), *Trends and issues in instructional design and technology* (3rd ed., pp. 321–332). Upper Saddle River, NJ: Pearson Education Inc.

Shute, V. J., & Ventura, M. (2013). *Measuring and supporting learning in games: Stealth assessment*. Cambridge, MA: The MIT Press.

Shute, V. J., Ventura, M., & Ke, F. (2015b). The power of play: The effects of Portal 2 and Lumosity on cognitive and noncognitive skills. *Computers & Education, 80,* 58–67.

Shute, V. J., Ventura, M., & Kim, Y. J. (2013). Assessment and learning of qualitative physics in Newton's Playground. *The Journal of Educational Research, 106,* 423–430.

Shute, V. J., Ventura, M., Kim, Y. J., & Wang, L. (2014). Video games and learning. In W. G. Tierney, Z. Corwin, T. Fullerton, & G. Ragusa (Eds.), *Postsecondary play: The role of games and social media in higher education* (pp. 217–235). Baltimore, MD: John Hopkins University Press.

Skinner, B. F. (1978). *Reflections on behaviorism and society*. Englewood Cliffs, NJ: Prentice-Hall.

Taylor, W. L. (1953). Cloze procedure: A new tool for measuring readability. *Journalism Quarterly, 30,* 415–433.

van der Meij, H., Albers, E., & Leemkuil, H. (2011). Learning from games: Does collaboration help? *British Journal of Educational Technology, 42*(4), 655–664.

Ventura, M., Shute, V., & Zhao, W. (2012). The relationship between video game use and a performance-based measure of persistence. *Computers & Education, 60*(1), 52–58. https://doi.org/10.1016/j.compedu.2012.07.003.

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.

Wouters, P., & van Oostendorp, H. (2013). A meta-analytic review of the role of instructional support in game-based learning. *Computers & Education, 60*(1), 412–425.

Chapter 5
The *Necessary Nine*: Design Principles for Embodied VR and Active Stem Education

Mina C. Johnson-Glenberg

1 The Two Profound Affordances

For several decades, the primary input interfaces in educational technology have been the mouse and keyboard; however, those are not considered highly embodied interface tools (Johnson-Glenberg, Birchfield, Koziupa, & Tolentino, 2014). Embodied, for the purposes of education, means that the learner has initiated a physical gesture or movement that is well-mapped to the content to be learned. As an example, imagine a lesson on gears and mechanical advantage. If the student is tapping the *s* on the keyboard to make the gear spin that would be considered less embodied than the student spinning a fingertip on a screen to manipulate a gear with a synchronized velocity. With the advent of more natural user interfaces (NUI), the entire *feel* of digitized educational content is poised to change. Highly immersive virtual environments that can be manipulated with hand controls will affect how content is encoded and retained. Now learners can spin a virtual hand crank with full arm movements (spin in directional circles) and engage with 3D complex gear trains from any vantage point desired. One of the tenets of the Embodied Games lab is that doing actual physical gestures in a virtual environment will have positive, and lasting, effects on learning in the real world. Tremendous opportunities for learning are associated with this latest generation of virtual reality (VR) (Bailenson, 2017) and one of the most exciting aspects of VR is its ability to leverage interactivity (Bailenson et al., 2008).

Immersive and interactive VR is in its early days of educational adoption. It will not prove to be a panacea for every disengaged student (as is sometimes touted in the popular press), nor do we expect future scholars to spend entire days in virtual classrooms [see fiction by Cline (2011)]. However, now that many of VR's affordability and sensorial quality issues are being addressed, it is reasonable to assume that VR experiences will become more ubiquitous in educational settings. When the

M. C. Johnson-Glenberg (✉)
Department of Psychology, Embodied Games, LLC, Arizona State University, Tempe, AZ, USA
e-mail: Minaj@embodied-games.com

P. Díaz et al. (eds.), *Learning in a Digital World*, Smart Computing and Intelligence, https://doi.org/10.1007/978-981-13-8265-9_5

demand comes, the community should be ready with quality educational content. There are few guidelines now for how to make optimal educational content in VR, so this chapter will begin by explicating several relevant pedagogical theories. The chapter includes two case studies of lessons that have been built already, and it ends with tenable design principles.

First, what makes VR special for learning? Two attributes of VR may account for its future contributions to education. These we call the two *profound affordances*. The first profound affordance is the *feeling of presence* which designers must learn to support, while not overwhelming learners. Slater and Wilbur (1997) describe presence as the feeling of being there. It is a visceral transportation that, in many individuals, occurs immediately; when surrounded in 360° by the virtualized unreal environment, players often lose sense of time. The second profound affordance pertains to *embodiment and the subsequent agency associated with manipulating content in three dimensions.* Manipulating objects in three-dimensional space gives a learner unprecedented personal control (agency) over the learning environment. We believe that gesture and re-enactments using the hand controls (and tracked fingers) will increase agency and positively impact learning. The basis for this prediction is the research on embodiment and grounded cognition (Barsalou, 2008). Although other methods for activating agency can be designed into VR learning environments (e.g., using eye gaze and/or speech commands), it may be the case that gesture plays a special role. Gesture kinesthetically activates larger portions of the sensori-motor system and motoric pre-planning pathways than the other two systems, and gesture may lead to stronger memory traces (Goldin-Meadow, 2011). Another positive attribute of engaging the learner's motoric system via the hand is that the use of hand controls is associated with a reduction in simulator sickness (Stanney & Hash, 1998).

VR for education should take full advantage of 3D object manipulation using the latest versions of handheld controllers (as well as, gloves and in-camera sensors to detect joints, etc.). The domain of gesture analytics in 3D is an area in need of more research and evidence-based design guidelines (Laviola, Kruijff, McMahan, Bowman, & Poupyrev, 2017). Because randomized control trials (RCT) are just starting to be published on immersive VR in education, it is not possible to do a review. Thus, this chapter focuses on design practices that the author has learned from creating content in mixed and virtual realities for the past 10 years. An early, and evolving, set of design principles for VR in education is provided at the end, and the hope is that the guidelines will assist this nascent field as it matures.

1.1 We All on the Same Vocabulary Page?

Below are different terms. Used by different communities. We should make sure we are all on the same page. This section defines some terms still in flux in the field: VR, presence, agency, and embodiment.

1.1.1 VR

In this chapter, the term VR refers to an immersive experience, usually inside a headset, where the real world is not seen for 360°. In VR, the learners can turn and move as they do in the real world, and the digital setting responds to the learner's movements. *Immersive VR* systematically maintains an illusion of presence, such that learners feel their bodies are inside the virtual environment. Being able to see evidence of the real world, even in the periphery, would mean the platform should be deemed either augmented or mixed reality (AR/MR).[1] A three-dimensional object or avatar displayed on a regular-sized computer monitor is never "VR"; we hope that educators soon stop conflating the terms and phenomena. It is preferred that PC monitor-supported content be referred to as virtual environment, or mediated or digital (some is even 2.5 dimensional), and that terms like IVR and VR be reserved for the immersive VR experience afforded by headsets (and CAVE systems with no real world components visible).

1.1.2 Presence

The term, presence, as it relates to education is also defined in a recent glossary by Dede and Richards (Dede & Richards, 2017). Presence is a… "particular form of psychological immersion, the feeling that you are at a location in the virtual world" (p. 5). The sensations are reported to be quite visceral. In a full immersion headset experience, the feeling of being in a different location is systematic and usually instantaneous. The presence associated with VR is one of the most immediate and well-documented phenomena. Thus, **presence is deemed the first profound affordance of VR**. Several surveys are available for assessing the amount of presence in a mediated experience (Makransky, Lilleholt, & Aaby, 2017; Slater & Wilbur, 1997).

1.1.3 Agency

Immersive VR has the ability to immediately transport the user to a limbically heightened emotional space that can have positive effects on attention and engagement; this is one reason why educators believe that learning will be positively affected. The *Google Expeditions* series relies on presence to immediately engage learners. A recent exploratory study explicitly states that the presence afforded by the 3D technology "opens up" the senses and mind for learning (Minocha, Tudor, & Tilling, 2017). Minocha et al. further hypothesize that because the students are in control of where they look and for how long, they can now follow "… their interest and curiosity,

---

[1] No space is devoted to CAVES in this chapter (environments with projected wall surfaces, or cubes, where reality is never present) because the cost of a CAVE is still prohibitive for most educational settings.

hence giving them a sense of control and empowerment over their own exploration". Whenever users feel they have control over the environment, they experience *agency*.

Agency underpins the second profound affordance of VR. Interestingly, this author (Johnson-Glenberg) considers the type of VR experience that is purely gaze-based to afford a relatively low amount of agency. (Although, it is still superior to a pre-programmed linear story.) When learners are able to manipulate more objects in the world, with more than a gaze-based lag time signal, we predict more precise and agentic behaviors will emerge. When learners feel they control multiple parameters in the learning scenario, they own the experience and may also take more responsibility for learning. Learning is defined as the building of knowledge structures. Many researchers hold that to build better knowledge structures one should be more agentic during the act of learning. The term agentic connotes that the user has individual (self-initiated) control and volition over the individual objects in the environment. In education, agency is considered a "self-directed construct" per the Snow, Corno, and Jackson (1996) provisional taxonomy of conative constructs.

The newest generation of VR includes synced hand-held controls. It is easier than ever to incorporate gesture and to manipulate objects in VR using this more Natural User Interface (NUI). The second profound affordance of VR is driven by the **ability to gesturally interact with virtual content in 3D** and receive realtime feedback. Our prediction is that hand controls will have long-lasting effects on the types of content, and the quality of the pedagogy, that can be designed into educational spaces. Instructors and researchers are no longer being constrained by commercially available tangibles or peripherals; it is now possible to build or print almost any desired tangible or vessel. (Need to pour from a specialized beaker in a chemistry experiment? You can 3D print the vessel, place trackers on it, add some actuators, and seamlessly simulate complex fluid dynamics—see http://meteor.ame.asu.edu/).

Evidence continues to accumulate that it is better for learners to be agentic and to kinesthetically engage with tasks rather than watching others engage. As an example, two participants were randomly assigned to one of two roles in a learning dyad, either active or observant (Kontra, Lyons, Fischer, & Beilock, 2015). Participants who were active and physically held bicycle wheels spinning on an axle learned more about angular momentum compared to those who observed the spinning wheel (Kontra et al., 2015). The second agentic example comes from a Jang, Vitale, Jyung, and Black (2016) study. In their yoked-pair design, one participant manipulated a virtualized 3D model of the inner ear, while another participant viewed a recording of the interaction. Results indicate that participants in the manipulation group showed greater posttest knowledge compared to the observation group.

1.1.4 Embodiment

Proponents of embodiment hold that the mind and the body are inextricably linked (Wilson, 2002). Varela et al. (1991) describe cognition as an "interconnected system of multiple levels of sensori-motor subnetworks" (p. 206). In this current chapter, the focus is on learning the content of science. Embodied learning theory has much to offer designers of VR content working with NUIs. The strong stance on embodiment and education holds that the body should be moving, not just reading or imaging, for a high level of embodiment to be in a lesson (Johnson-Glenberg, 2017; Johnson-Glenberg & Megowan-Romanowicz, 2017). When a motoric modality is added to the learning signal, more neural pathways are activated and this may result in a stronger learning signal, or memory trace. Several researchers posit that incorporating gesture into the act of learning should strengthen memory traces (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007; Goldin-Meadow, 2011). It may be the case that adding more modalities to the act of learning (beyond the usual visual and auditory ones) will further increase the strength of the memory trace. The modality of interest in this chapter is gesture.

Throughout this chapter, the term gesture is used to mean both the movement as a communicative form, and the action used to manipulate virtual objects in the VR environment. The "gesture-enhancing-the-memory-trace" argument can also be framed as one of levels of processing, which is a well-studied concept in cognitive psychology (Craik & Lockhart, 1972), as is, learning by doing. Learning by doing further supported by a large body of research on Self Performed Tasks (Engelkamp & Zimmer, 1994). In those studies, when participants *performed* short tasks, the task-associated words were better remembered compared to conditions where the participants read the words, or saw others perform the tasks.

Perhaps only concrete words and actions are recalled via gesture? What about abstract words? Repetto, Pedroli, and Macedonia (2017) instructed participants with 30 novel abstract words in a foreign language. The encoding conditions were (1) verbal—read word out loud, (2) picture encoding—read word with a concurrent static graphic image, and (3) gesture encoding—read word while observing a 2-s-long video of someone performing metaphoric gestures that connoted meaning. The group exposed to the gesture encoding videos displayed better word recall. Repetto et al. stipulate that training should occur over multiple days (many of their experiments repeat over three to five days) because procedural learning via gesture takes long(er) to cohere, compared to other types of encoding. Thus, it may be worth the extra trials and training time, because information retrieval post-gestural encoding was also superior in speed of recall and resistance to decay.

Research on non-mediated forms of gesture in the educational arena has also been fruitful. As an example, when teachers gesture during instruction, students retain and generalize more of what they have been taught (Goldin-Meadow, 2014). Congdon et al. (2017) showed that simultaneous presentation of speech and gesture in math instruction supported generalization and retention. Goldin-Meadow (2011) posits that gesturing may "lighten the burden on the verbal store" in a speaker's mind. Gesturing may serve to offload cognition (Cook & Goldin-Meadow, 2006). Gestures may aid learners because learners use their own bodies to create an enriched representation of a problem, which is then grounded in what have been called "physical metaphors" (Alibali & Nathan, 2012; Hostetter & Alibali, 2008; Nathan et al., 2014). In addition, using gesture requires motor planning and this activates neural activations, and multiple simulations, even before the action is taken. Hostetter and Alibali (2008) posit that gesture first requires a mental simulation before movement commences, at that time motor and premotor areas of the brain are being activated in action-appropriate ways.

1.1.5 Here Is First Mention of Congruent

The gesture should be congruent to the content being learned (Black, Segal, Vitale, & Fadjo, 2012; Segal, Black, & Tversky, 2010). That is, the gesture should map to the instructed concept. For example, if the student is learning about the direction and speed of a spinning gear, then it would be important for the student's spinning hand gesture to go in the same direction, and initiate the approximated speed of the virtual gear on screen (Johnson-Glenberg, Birchfield, Megowan-Romanowicz, & Snow, 2015). Gestures may provide an additional code for memory (again, strengthening the trace) as well as adding additional retrieval cues. Learners with stronger memory traces should do better on post-intervention tests.

In a digital VR world, gesturing with a human-looking avatar hand may have special affordances that further increase the sense of agency. It is known that using one's hands to be in control of the action on screen can attenuate simulator sickness (Stanney & Hash, 1998). Research further supports that users quickly begin to treat their avatars as their real bodies (Maister, Slater, Sanchez-Vives, & Tsakiris, 2015). With the advent of VR hand controls, where gestures can be fairly easily mapped, and more embodiment can be designed into lessons, it seems timely to revisit and clarify an earlier taxonomy on embodiment for education.

2 Taxonomy of Embodiment for Education in VR

As with all theories, there are inclusive (weak) ones that start the spectrum, and exclusive (strong) ones that end it. One inclusive theoretical stance on embodied learning would be that any concept that activates perceptual symbols (Barsalou, 1999) is, by its nature, embodied. Following this stance, all cognition is embodied because our earliest knowledge is gathered via the body and its interactions with the environment, even new concepts that are later imagined. The environment's affordances (Gibson, 1979) shape and constrain how our bodies interact, ergo, cognition continues to be formed and expanded by these interactions. In an inclusive interpretation, according to some researchers, cognition would be broadly defined to include all sensory systems and emotions (Glenberg, 2010; Glenberg, Witt, & Metcalfe, 2013). A more exclusionary stance is one that distinguishes between low and high levels of embodiment. For a lesson to be deemed highly embodied, the learner would need to be *physically active;* the learner would have to kinesthetically activate motor neurons. Some principles for designing embodied education into MR platforms have been suggested (Lindgren & Johnson-Glenberg, 2013), and several AR design principles have been proposed (Dunleavy, 2014); however, there are currently no design guidelines for VR that are based on embodiment. Given the new affordances of VR hand controls, it seems timely to reframe some of this lab's previous embodied principles.

A more exclusionary definition of embodiment for education was proposed by this lab in 2014 (Johnson-Glenberg et al., 2014a) and updated recently (Johnson-Glenberg & Megowan-Romanowicz, 2017). That taxonomy posited four degrees of embodiment based on three constructs: (a) amount of sensori-motor engagement, (b) how congruent the gestures were to the content to be learned, and (c) amount of "immersion" experienced by the user. Each construct will be expanded upon below. Finally, a new cube of embodiment will be proposed.

2.1 Sensori-Motor Engagement

In terms of sensori-motor engagement via gesture (construct a), the first distinction relates to the magnitude of the motor signal. This means that a larger movement, e.g., a gross arm movement would activate more sensori-motor neurons compared to a smaller one like swiping a finger across a small screen. The magnitude of the movement should probably be part of the metric, but it is perhaps less important than whether the gesture is well-matched (congruent) to the content to be learned (construct b). A small, yet highly congruent movement may be just as effective as a large one that is only loosely related to the learning concept. That is an experiment that needs to be conducted.

2.2 Congruency of the Gesture

Construct b refers to the congruency of the gesture, that is, the movement should be mapped to, related to, the concept to be learned. The gesture should support the gist of the content and give meaningful practice to the learning goal; however, the movement need not be a perfect isomorphic match. In the spinning gears example, a mediated lesson was created to instruct in mechanical advantage for gear systems (Johnson-Glenberg et al., 2015). The *Microsoft Kinect* sensor was used to capture the direction and speed of the spin of the learner's arm. The learner extended his/her arm in front of the body and rotated it around the shoulder joint. That movement drove the first gear in a simulated gear train. Using distance from shoulder joint to wrist joint, the average diameter of the driving gear was mapped to the learner's body; when the learner altered the size of the physical spins, that action altered the size of the gear on screen in real time. Using the learner's real time wrist speed, the velocity of the gear spin was also mapped in real time. **Congruency means a large overlap between the action performed and content to be learned**. In the above study, the learners who understood mechanical advantage (on a content knowledge test) also showed greater competency during gameplay. The better testers also consistently chose the correct diameter gear during the virtual bike race during play. This is an example of how gesture can be part of both the learning situation and assessment wrapped in virtual gameplay.

2.3 Immersion/Presence

Construct c has been called *sense of immersion* in previous articles describing the Johnson-Glenberg embodiment taxonomy for education (Johnson-Glenberg, Birchfield, Koziupa, & Tolentino 2014; Johnson-Glenberg & Megowan-Romanowicz, 2017). However, Mel Slater's lab posits that immersion is a non-subjective property of the technological system and should not be considered a *sensation*. Immersion is composed of various system attributes, e.g., Field of View (FOV), fidelity to environment, etc. Slater and Wilbur (1997) distinguish between presence and immersion, positing that presence is what is subjectively felt by the user. Slater and Sanchez-Vives (2016) concede the two terms are "subjective correlates". This author is guilty of often conflating the two terms. Slater and others (Witmer & Singer, 1998) assert that the two terms should be kept separate because presence is always a subjective experience. But, we agree the two terms are inextricably "tangled" (Alaraj et al., 2011), and given the high fidelity and immersive affordances of the current spate of immersive VR technologies, it may be appropriate to assume the majority of users will be in high fidelity and highly immersive VR environments (our lab focuses on high-end, non-mobile phone headsets). As the amount of immersivity in the technology begins to asymptote, perhaps we can conflate the two terms into the one called *presence* when assessing psychological/educational experiences? The levels of quality for optics, lag, and audition are impressive; we believe they are sufficient for the majority of users to suspend disbelief and feel deeply translocated.[2]

Thus, the author proposes using the one term *presence* to also connote a very high degree of immersion as well, because the amount of immersion is universally high in the current generation of immersive 3D VR. For VR, this chapter continues with a fusion term of *immersion/presence* to bridge to the future. Under the construct of immersion/presence, there are subsumed other factors or corollaries that are critical to learning, e.g., motivation and prior knowledge, which are clearly important. Although, many of these factors are not under the control of lesson designers. One might experience low presence in a lesson if prior knowledge were extremely low and inadequate for the task.

Several new taxonomies for embodiment are being proposed that do not include the third dimension of immersion/presence (Skulmowski & Rey, 2018). In many ways, a two axes model makes for a tidier taxonomy. However, we believe that to reframe the embodied taxonomy for education for 3D immersive VR, a construct for immersion/presence is crucial because presence is one of the unique and profound

---

[2] This is not to say the distinction between immersion and presence should never be used for MR and/or AR systems. Playing games on smartphones, which are bordered, small screen experiences (not 360) do seem to still induce hours of "presence" in many users.

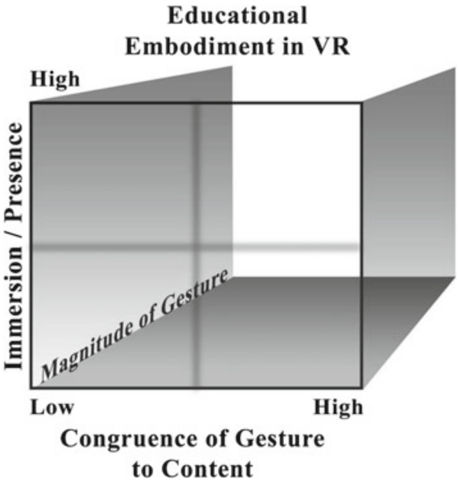
affordances of VR. The original table (a 3 × 8 matrix) that partitioned the three constructs into high and low spaces can be found in Johnson-Glenberg and Megowan-Romanowicz (2017).

3 3D Figures for 3D Learning

The reconceptualization of the graphic for embodiment in VR takes into account the continuous nature of the three constructs. Figure 1 also maintains the concept of immersion/presence. The crosshairs in the middle allow the reader the opportunity to partition the space into more tractable low and high construct areas. Figure 1 could even be imagined as eight sub-cubes. Because magnitude of the gesture (i.e., the amount of sensori-motor engagement) may prove to be the least predictive construct for content comprehension, it is relegated to the Z axis. The Z axis, or depth, is usually more difficult to conceptualize in a graphic. The goal for graphics like these is to aid researchers and designers in visualizing embodiment in educational content and aid the community in using the same terminology. These graphics should also spur researchers to assess the orthogonality of the constructs and to design randomized controlled trials to explore the variance associated with each axis (as well as higher order interactions).

The main take away is that a lesson can be deemed high on the embodiment scale if the gestures are congruent and meaningful, and if the lesson induces immersion/presence. In much of the past research on learning in VR, e.g., see Guiterrez et al. (2008), the focus has been on the technology and short shrift has been given to learning pedagogies supporting the lessons. Designers and users of VR should be

Fig. 1 Cube of Embodiment in Educational VR Content (With permission from Johnson-Glenberg and Romanowicz (2017) from *Frontiers*)



more aware of felicitous learning theories, so a concise summary of three relevant theories, used by this lab, has been included.

4 VR and Education Theories

Scholars have been asking for educational research on VR for some time (Mikropoulos & Natsis, 2011), but the resources and affordable technologies were not readily available. Up until 2016, most of the literature on VR and education was based on proprietary VR software and hardware. The research labs, the military, or the commercial companies created in-house products that were too expensive, and unwieldy for public consumption. In 2016, two sets of high-end headsets with hand controllers (Oculus *Touch* and HTC *VIVE*) came to the market. Studies on gesture in VR are slowly coming to light.

In these early days, trial and error play an outsized role in design. Education researchers borrow heavily from entertainment designers, who focus on engagement, and not necessarily on retention of content. This begs the question of whether some rules in the entertainment domain, like "never break immersion", should be violated if higher order learning is to occur? The two lessons highlighted in the next sections were designed using components of three education theories that lend themselves to creating gesture-controlled multimedia content. The three theories are constructivism, guided inquiry and embodied cognition.

4.1 Constructivist Learning Theory

Constructivism builds off of Dewey's (1966) concept that education is driven by experience. Piaget (1997) further describes how a child's knowledge structures are built through exploratory interactions with the world. Environments such as VR can provide opportunities for learners to feel present in goal-driven, designed activities. Further definitions are culled from a teacher's textbook (Woolfolk, 2007). Common elements in the constructivist perspective include:

1. Embed learning in complex, realistic, and relevant learning environments.
2. Provide social negotiation and shared responsibility.
3. Support multiple perspectives and multiple representations of content.
4. Knowledge is constructed (built upon)—the teaching approach should nurture the learner's self-awareness and understanding of ongoing construction.
5. Encourage ownership in learning. (p. 348)

Point 2 regarding social negotiation is important in education. It should be noted that it is still expensive to implement multiuser, synchronized learning spaces. Educational instances of real-time, multiuser social negotiations in VR are coming though (for an update on multiuser VR in education, see Slater & Sanchez-Vives, 2016). In scaffolded, virtual STEM environments, the learners start with simple models and interact to create more complex ones over time. Learners receive immediate feedback and know they are the agents manipulating the objects. They know they are in charge of the constructing. When a lesson is appropriately designed, with incrementally increasing difficultly, and includes evaluative, real-time feedback, then learners are encouraged to become more metacognitive. Learners become evaluative about their output. They can re-submit or reconstruct models multiple times. In this way, agency and ownership are encouraged. Active learning is especially important in the STEM domain where the majority of young learners drop out from studying that subject area over time (Waldrop, 2015).

4.2 Guided Inquiry

Guided inquiry emerged in the late 1980s as an effective practice because it had been shown that free, exploratory learning, on its own, could lead to spurious hypotheses. Minimally guided instruction is “less effective and less efficient” (Kirschner, Sweller, & Clark, 2006), at least until a learner has a sufficient amount of prior knowledge. Students benefit from pedagogical supports that help them construct conceptual models, or knowledge structures (Megowan, 2007). VR can be an important supportive tool in the guided learning domain because real-world distractions are mitigated. Guiding learners towards accurate deductions does not mean hand-holding. It means giving just enough information so that the final deduction is made by the students, and they take ownership over what they have learned. Clearly some cognitive effort is needed for learning “to stick”; these concepts are in line with the desirable difficulties literature (Bjork, 1994; Bjork & Linn, 2006), and levels of processing research.

4.3 Embodied Learning

Human cognition is deeply rooted in the body’s interactions with the world and our systems of perception (Barsalou, 1999; Glenberg et al., 2013; Wilson, 2002). It follows that our processes of learning and understanding are shaped by the actions taken by our bodies, and there is evidence that body movement, such as gesture, can serve as a “cross-modal prime” to facilitate cognitive activity (e.g., lexical retrieval) (Hostetter & Alibali, 2008). Several studies by Goldin-Meadow’s group have shown a direct effect of gestures on learning (Goldin-Meadow, Cook, & Mitchell, 2009). Recent research on embodied learning has focused on congruency (Johnson-Glenberg, Birchfield, Tolentino, & Koziupa, 2014; Segal, 2011), which posits an alignment of movements or body positioning (the body-based metaphor—see Lindgren’s work) and within specific learning domains [e.g., learning about centripetal force and circular motion by performing circular movements as opposed to operating a linear slider bar (Johnson-Glenberg, Megowan-Romanowicz, Birchfield, & Savio-Ramos, 2016)]. Virtual and mixed reality environments afford the opportunity to present designed opportunities for embodied interactions that elicit congruent actions and allow learners opportunities to reflect on embodied representations of their ideas (Lindgren & Johnson-Glenberg, 2013).

Embodied learning is probably most effective when it is *active*, and the learner is not passively viewing the content, or watching others interact with manipulables (Abrahamson, 2009; Abrahamson & Trninic, 2015; Kontra et al., 2015). If the learner is induced to handle the physical content, or to manipulate the content on screen then they must be physically active and moving the body (which activates more sensori-motor areas). The new VR hand controls will allow for enactive engagement and high levels of embodiment in lessons. Using virtual content, teachers will now be less constrained by having to purchase specific physical manipulables. What is needed now is a set of design guidelines for educational content being created for VR.

5 Prudent VR Guidelines Thus Far

For the most part, immersive VR education studies have occurred primarily in adult populations (Freina & Ott, 2015). Health and medicine have been leading the way, with everything from surgical training of craniofacial repairs (Mitchell, Cutting, & Sifakis, 2015) to behavioral change interventions related to PTSD (Rizzo et al., 2010). We are confident that VR will prove to be very useful, but it is currently under-utilized due to price. We predict that when the Standalone headsets (e.g., *Oculus GO*) which do not require phones or separate CPU's, become more affordable, then immersive VR experiences with a hand controller will become popular for classroom use. At that time, educators will ask—where is the quality content?

What *will* high quality pedagogy in VR look like? Not everything in 2D needs to be converted to 3D. When designing for VR for education, Dalgarno and Lee presciently published five affordances for three-dimensional VR environments (Dalgarno & Lee, 2010). We agree with their five and those mesh nicely with Bailenson's below (2016). He posits that VR should be used in situations where it is most advantageous (Bailenson, 2016). Situations that are:

- **Impossible**—For example, you cannot change skin color easily, but in VR you can inhabit avatars with different skin colors with profound results (Banakou, Hanumanthu, & Slater, 2016; Hasler, Spanlang, & Slater, 2017). You cannot perceive a photon going directly into your eye in the classroom, but in the next section we describe a VR simulation doing just that.
- **Expensive**—You cannot easily fly your whole school to Machu Picchu.
- **Dangerous**—You would not want to want to train emergency landings by crashing real airplanes.
- **Counterproductive**—You should not cut down an entire forest to instruct on the problems of deforestation.

Results from the Embodied Games lab's previous mediated research (Johnson-Glenberg et al., 2014; Johnson-Glenberg & Megowan-Romanowicz, 2017; Johnson-Glenberg, Savio-Ramos, & Henry, 2014) support the hypothesis that when learners perform actions with agency and can manipulate content during learning, they are able to learn and retain STEM knowledge better compared to learners exposed to low embodied content. Thus, our two affordances for education can be meshed with the Bailenson's more general ones. The design principles in the next section highlight how tracked gestures could be incorporated into learning.

6 Design Principles for Embodied VR Education

Adroitly meshing quality pedagogy with compelling gameplay is a far more arduous and heart-breaking endeavor than one would initially suspect. It is very difficult to create learning games that are both (a) educational and (b) sustainably entertaining. When these goals collide, this lab has opted to maintain high educational standards, and to let the entertainment aspects wane. This means that the player (student) needs to come to the task with an expectation of perseverance. It also means the starting point of serious game engagement is fundamentally different from the starting point of entertainment gameplay. Educational game designers *do* need to keep the game engaging, but we should rightfully be wary of adopting media design guidelines whole cloth from the entertainment world. Some of the end goals of entertainment are prolonged time and repeated visits. Paradoxically, an effective educational game that instructs well would not necessarily be re-visited multiple times by the same learner (unless the learner needed an occasional refresher), and should never prompt for in-game purchases.

Porting learning content to the latest XR environment (the new term for MR, AR and VR) will add another layer of complexity to all learning games, until the conventions and UI components become second nature. This author has created several epically flawed "edu-games" after 20 years of designing and developing. Designers must work against the biases they encountered in the world of 2D, and not bring them into the world of 3D design. Because I am a human, who is shaped as a cognitive psychologist hammer, it is my duty to bang away on the absence of learning scientists on many game design teams. Our absence leads to several easily remediated flaws, such as, pacing issues (typically massed, rarely spaced), ill-conceived reward structures (variable, when interval is more appropriate), and surface-level assessments (often unimaginative, declarative knowledge, dual choice questions at the end of the module). The advice is to procure a strong, multiskilled team and use your funds where they are most needed. In the education domain, probably playtesting is more important than polished graphics.

The original 18 design guidelines in this section have been pulled together with pedagogy and optimal learning in mind. The final *Necessary Nine* at the very end of the chapter have been further culled with financial constraints and development realities in mind. Also, they can be taped to a wall on one page.

Multiple articles and books addressing principles of multimedia (Mayer, 2009) and how to design games in 2D exist. For examples see Squire (2008), Salen and Zimmerman (2004), and Schell (2014). The set below is one of the first for VR and education, especially with a focus on using hand controls for STEM learning. Our focus is on making VR content that is engaging and embodied. To that end, these design guidelines will continue to be updated and refined as the technology and its affordances are updated and refined. Each guideline ends with a sentence of support or a citation should readers want to dive deeper. A version of these guidelines first appeared in Johnson-Glenberg (2018).

6.1 Education in VR—General Guidelines

- **Assume every learner is a VR newbie—*start slow***
  - Not everyone will know the controls. Not everyone knows to look around. Users are now in a sphere and sometimes need to be told to turn their heads. However, they should not turn too far, nor too quickly. Do not place important interface, HUD components, or actionable items, too far from each other.
  - The user should not capture butterfly #1 at 10° and then capture butterfly #2 at 190°. Be gentle with users' proprioceptive systems (where the body is in space). Watch out for large body-action disconnects, e.g., the learner is standing, but the avatar is running, or lying in a bed. If the content includes varying levels of difficulty, allow the user to choose the level at the start menu. This also gives a sense of agency. Our "start slow" advice comes from years of designing educational content.
- **Introduce User Interface (UI) components judiciously, fewer is better**
  - Keep the screen clean. Permanent objects (i.e., a timer that stays center-screen as the player turns head) will break the presence/immersion feel. When users build the first fireworks in our fireworks/chemistry lesson, they can only make one stage rockets. The more complicated multistage components are not available in the interface until users show mastery of the simpler content. Add visual complexity when the user is acclimated and ready (Johnson-Glenberg et al., 2014).
- **Scaffold—introduce cognitive steps one at a time**
  - Build up to cognitive complexity (Pea, 2004) as well. In the electric field series[3] of seven mini-games, users are not immediately exposed to the multivariable proportionality of Coulomb's Law. Each component, or variable, in the Law is revealed one component at a time and reinforced via gameplay. Users explore, and eventually master each component successively before moving to the final

---

[3] Also www.embodied-gams.com – or https://www.youtube.com/watch?v=eap7vQbMbWQ.

lesson that incorporates all the previously learned content and culminates in the formation of lightning (Johnson-Glenberg & Megowan-Romanowicz, 2017).

- **Co–design with teachers**
  - Co-design means early and with on-going consultations. Let the teachers, Subject Matter Experts (SMEs), and/or clients play the game at mid- and end stages as well. Playtesting is a crucial part of the design process. Write down all comments made while in the game. Especially note where users seem perplexed, those are usually the breakpoints.
  - Working with teachers will also ensure that your content is properly contextualized (Dalgarno & Lee, 2010), i.e., that it has relevance in, and is generalizable to the real world and to important content standards.
- **Use guided exploration**
  - Some free exploration can be useful in the first few minutes for accommodation and to incite curiosity, but once the structured part of the lesson begins, it is your job to *guide* the learner. Guide using constructs like pacing, signposting, blinking objects, constrained choices, etc. To understand why *free* exploration as an instructional construct has not held up well in STEM education, see Kirschner, Sweller, and Clark (2006).
- **Minimize text reading**
  - Rely on informative graphics or mini-animations whenever possible. Prolonged text decoding in VR headsets causes a special sort of strain on the eyes, perhaps due to lens muscle fatigue or the vergence-accomodation conflict. In the Catch a Mimic game (next section), players do not read lengthy paragraphs on butterfly cocoons, instead a short cut-scene animation of butterflies in chrysalis and quickly emerging is displayed.
- **Build for low stakes errors early on**
  - Learning often requires errors to be made. Learning is also facilitated by some amount of cognitive effortfulness.
  - In our recent Catch a Mimic game, the player must deduce which butterflies are poisonous, just like a natural predator must. In the first level, the initial butterflies that appear on screen are poisonous. Eating them is erroneous and slightly depletes the player's health score, but there is *no other way* to discern toxic from non-toxic without feedback on both types. Some false alarms must be made. Later in the game, errors are weighted heavier. In psychology, this is called 'learning from errors' (Metcalfe, 2017). In the learning sciences, it has been called productive failure (Kapur, 2016).
- **Playtest often with both novices and end-users**
  - It is crucial that designers playtest with multiple waves of age-appropriate learners for feedback. This is different from co-designing with teachers.

  - Note, playtesting with developers does *not* count. Human brains learn to reinterpret visual anomalies that previously induced discomfort, and over time users movements become more stable and efficient (Oculus, 2018). Developers spend many hours in VR and *they physiologically respond differently* than your end-users will.

- **Give players unobtrusive, immediate, and actionable feedback**
  - This does not mean *constant* feedback (Shute, 2008). Feedback should be paced because it takes time for the cognitive adjustments to be integrated into the learner's ongoing mental model. This leads to the next guideline on reflection.

- **Design in opportunities for reflection (it should not be all action and twitch!)**
  - Education game designers are currently experimenting with how to do this in VR. Reflection allows the learner's mental model to cohere. Some ongoing questions include: Should the user stay in the headset or not? How taboo is it to break immersion? Should short quizzes be embedded to induce a retest effect (Karpicke & Roediger, 2008)? Perhaps screencasting with dyads could work—one partner outside the headset asks questions of the one inside?

- **Encourage collaborative interactions**
  - Synced, multiplayer experiences are still expensive, but their creation is a worthy goal. Until the cost drops, designers should explore workarounds to make the experience more social and collaborative. Some ideas include: using a preprogrammed non-player character (NPC), having a not-in-headset partner interact via a screencast on a handheld, or building sequential tasks that require back-and-forth asynchronous activities. A classroom collaboration and cooperation classic is Johnson and Johnson (1991).

6.2 Using Hand Controls/Gestures

The following design guidelines focus on using the hand controllers in VR for learning.

- **Use the hand controls to encourage the learners to be "active"**
  - Incorporate into lessons opportunities for learners to make physical, kinesthetic actions that manipulate content. Where appropriate, try to include representational gestures and/or re-enactments.
  - In or previous research, the group that was instructed in centripetal force and made kinesthetic circles (either with the wrist or arm) retained more physics knowledge, compared to the group that made low embodied, less active motions (Johnson-Glenberg et al., 2014). Active learning has been shown to increase STEM grades by up to 20% (Waldrop, 2015).

- **How can a body-based metaphor be applied?**
  - Be creative about ways to incorporate kinesthetics, or body actions, into the lesson. At first blush, it may not be apparent how to make a traditional bar chart become more embodied. But with a VR hand control, it is easy for the learner to use a gesture to fill a bar to the correct height. An upward swipe is also congruent with our cultural concept of higher (see Abrahamson's work for embodied and mediated examples of proportional reasoning https://edrl.berkeley.edu/edrl_publications). In the Munch a Mimic game, students are asked make a prediction about species survivability using the hand controls (see Fig. 5, next section). We also note that prediction is a well-researched metacognitive comprehension strategy (Palinscar & Brown, 1984).
- **Congruency**
  - The gesture/action should be congruent, i.e., it should be well-mapped, to the content being learned (Black et al., 2012; Johnson-Glenberg & Megowan-Romanowicz, 2017). The action to start a gear train spinning should involve moving the hand or arm in a circle with a certain velocity, it should not be pushing a virtual button labeled "spin" (Johnson-Glenberg et al., 2015).
- **Actions strengthen motor circuits and memory traces**
  - Performing actions stimulates the motor system and appears to also strengthen memory traces associated with newly learned concepts. Refer to the previous section on embodiment for multiple citations, or read Johnson-Glenberg and Megowan-Romanowicz (2017) for an example of a mixed reality RCT where active and embodied mini-games resulted in significant learning gains and increased engagement scores.
- **Ownership and agency**
  - Gestural control gives learners more ownership of and agency over the lesson. Agency has positive emotional affects associated with learning. With the use of VR hand controls, the ability to manipulate content and interactively navigate appears to also attenuate effects of motion sickness (Stanney & Hash, 1998).
- **Gesture as assessment—both formative and summative**
  - Design in gestures that reveal the state of the learner's mental model, both *during learning* (called formative or in-process) and *after the act of learning* (called summative).
  - For example, you might prompt the learner to demonstrate negative acceleration with the swipe of a hand controller. Does the controller speed up or slow down over time? Can the learner match certain target rates? This is an embodied method to assess comprehension that includes the added benefit of reducing guess rates associated with the traditional text-based multiple choice format. For an example of hand movements showing vector knowledge on a tablet, see the *Ges-Test* in Johnson-Glenberg and Megowan-Romanowicz (2017).

- ***Aspirational*****—personalized, more adaptive learning**
  - Finally, this is acknowledged to cost more, but the learning content level should reside a fraction beyond the user's comprehension state, also known as the learner's Zone of Proximal Development (ZPD) (Vygotsky, 1978).
  - Gesture research on younger children shows they sometimes gesture knowledge before they can verbally state it. Gesture-speech mismatches can reveal a type of readiness to learn (Goldin-Meadow, 1997). Thus, gestures can also be used as inputs in adaptive learning algorithms.
  - Adding adaptivity (dynamic branching) based on performance is more costly, but it is considered one of the best practices in educational technology (Kalyuga, 2009); it is something to strive for.

7 Case Studies: Two Examples

This section highlights relevant education theories and design principles in two case studies. The first example showcases some of the changes that occurred as 2D content was repurposed to a 3D VR lesson. The second example highlights the design techniques of construction and guided exploration. Both of the VR lessons are based on theories of guided inquiry and embodied learning. Scaffolding, reflection, and creative assessments are strongest in the first lesson on natural selection. Constructivism, agency, and guided exploration will be further discussed in the second lesson on chemistry via fireworks.

7.1 Example 1. The Natural Selection Game: Reconceptualizing 2D Content into a 3D VR Lesson

This project began as a 2D assessment tool to measure knowledge gained after watching a giant screen movie, *Amazon Adventure*.[4] One of the key science topics in the movie was Batesian mimicry. The tablet-based test was designed to *not instruct* in the topic, but rather to assess whether players became more adroit at picking out non-poisonous butterflies over time, as the levels increased in difficulty. This version of the pattern matching game ended with several open-ended and multiple choice questions. Design was constrained because we could not include explicit text that described how mimicry occurred. We have since added text to make this a standalone lesson. This earlier 2D assessment was given at multiple time points around movie viewing: pre-, post-viewing and after a two week delay.

---

[4] The movie is called *Amazon Adventure*. The funding agency for the assessment tool was National Science Foundation, grant # 1423655. A WebGL version of the game can be played at www.embodied-games.com.

7.1.1 Tablet Version of the Natural Selection Game

The butterflies would spawn from the right side of the screen and the background of a forest would slowly scrolls to the left. The instructions read, “You are a bird trying to eat as many non-poisonous butterflies as possible”. A finger-tap on a butterfly made it disappear. Immediate feedback was given (visually, not auditorially as this was a test taken by entire classrooms). Persistent feedback was displayed on top of the screen as to whether the choice was poisonous (red outline boxes), or non-poisonous (green outline boxes) showed tapped butterflies. As the levels progressed, the non-poisonous butterflies naturally selected to more closely resemble the poisonous butterflies. On the *Kindle FIRE* 10 tablet, the actionable play space was only 7.0 in. (diagonal) and so no distractors were included, i.e., falling leaves, particles in foreground, moving water, as there was not enough room.

The next step was to turn the assessment tool into an engaging, instructional game on the topic of natural selection. The format should match a ubiquitous digital form factor in schools, but not move to a smaller screen because the game depends on detailed visual pattern matching. Thus, a PC format with mouse input was chosen.

7.1.2 PC Version of the Natural Selection Game

In the current PC version of the Natural Selection Game (release February, 2019), the mouse controls the location of a net. A mouse click captures a butterfly, see Fig. 2. The new opening narrative changed and states, “You are a zookeeper capturing butterflies to feed to your birds”. The scroll to the left mechanic did not feel appropriate for the larger, computer monitor (average diagonal 16 in.), so now the butterflies spawn and fly out of a central bush, and higher resolution is possible. Because the game would eventually move to VR the team decided that flying and swooping as a bird could make the player nauseous, and so the bird POV was abandoned.

The PC version is not constrained to be an assessment tool. The re-design to an instructional lesson includes more embedded text. Appropriate game elements to enhance engagement were included, e.g., moving waterfalls, visual distractors, and audio. Chirping birdsong helps to increase presence. Feedback is handled differently on the PC. We wanted to declutter the screen so we removed the permanent feedback at the top of the screen. Now on the bottom right of the screen (pinned to the world, BUT not to the HUD) is performance feedback that is numerical. In addition, audio feedback, as positive or negative sounds upon collision with a butterfly has been added. Now, gameplay encourages the player to remember the butterfly that was just captured, feedback, as a green heart or red skull, shows up upon collision on the central screen for 1.5 s. On the bottom right is persistent (unpinned) numerical feedback on type of butterfly captured. The ongoing count is displayed next to either

Fig. 2 PC version butterflies spawn from a central bush and fly towards the player. The screen no longer scrolls, but the moving waterfall keeps the background from feeling very static

the green heart icon (non-poisonous) or the red skull (poisonous).[5] The timer restarts at 60 s for each of the six levels.

7.1.3 VR Version of the Natural Selection Game

The background and moving assets (butterflies, etc.) were then rendered into 3D. The VR version has graphics that curve around 360°. However, all the action is constrained to occur in the "central play arc" of approximately 170°. Figure 3 shows a portion of the VR playspace. Feedback is now located closer to the spawning bush and is pinned to the world (not HUD)—this means if you turn around 180°, you will only see the forest and stream. This maintains presence/immersion. The waterfall now continues as a stream that encircles you as the player. Sound is omni-directional. Although players can turn all the way around and see trees, earth, and sky, no butterflies or clickable action content appear "behind" the players because we do not want them to spin around, get dizzy, or become tangled in wires. At the bottom of Fig. 3, note the ghostlike avatar hand that is mapped to the human player's hand and wrist movements. In this *Oculus* version *(Rift* and *GO*), the hand grips around the net handle. The net is fully articulated in three axes.

---

[5] Late stage playtesting with colorblind males, revealed that red and green remained poor choices for feedback. Even though we knew this at the onset and tried to compensate with a second feedback signal of shape, i.e., two different icons: heart versus skull. The images were just too small to be easily distinguished, and this needs to be addressed in the next version.

Fig. 3 The VR version with flowing water and an articulated avatar hand and wrist

7.2 *Creative and Embodied Assessments*

For both the PC and VR versions an interactive assessment was created. Population dynamics can be a difficult concept to teach; we believe that its instruction must not "necessarily be quantitative" (Schaub & Abadi, 2011). Middle schoolers can make inferences and predictions about joint likelihoods without memorizing statistical formulae. Prediction is one of a set of powerful and well-researched comprehension strategies (Rosenshine & Meister, 1994). Primary school students are capable of making predictions in the middle of STEM texts and then evaluating the outcomes by the end of the text (Palinscar & Brown, 1984). The goal was to include an embodied prediction in the VR environment. It is straightforward to track the hand controllers in 3D. This opens up multiple opportunities to include a large spectrum of gestures and re-enactments for the purposes of assessment (and instruction). A predictive question was created that would adhere to many of the design principles in the chapter, including low stake errors with feedback, being active, and using congruent movements (*swipe upwards to connote an increase*). The question's answer should provide a snapshot of the learner's comprehension state, while also encouraging the learner to think deeply about outcomes (i.e., being predictive).

Figure 4 shows the interactive bar chart prompt, after an active submission. That is, the first green-filled bar is animated to show it filling up and it is then locked in the HIGH position. The learner must make the best guess as to the survivability of the next four species, i.e., the poisonous butterfly (#2) and the three non-poisonous butterflies to the right (#3, #4 and #5). Dragging the blue oval moves the green fill in the bars (which snap to either low, medium, or high positions). When learners are

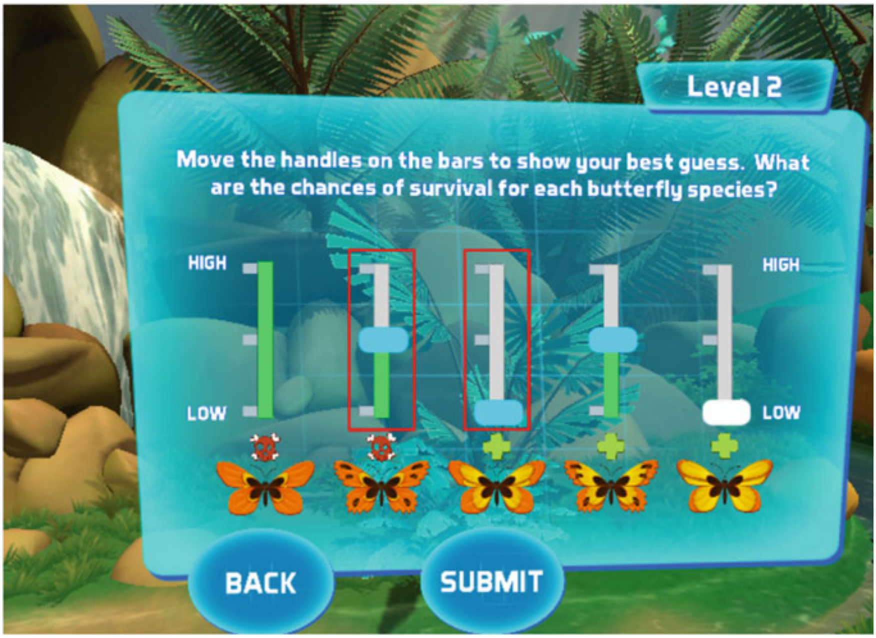


Fig. 4 Interactive assessment in both 2D and 3D VR versions—with corrective feedback. The red boxes around butterflies #2 and #2 connote incorrect

satisfied with their decisions, they click on the submit button. Learners are allowed three incorrect submissions before an animation shows the correct answer.

7.3 Example 2. A High Embodied VR Lesson with Hand Controls. Topic: Chemistry/Physics

Example 2. CHEMISTRY—Fireworks

The second example is special because it is multiplayer. Multiplayer mode is still expensive, but it is coming! This module was designed in 2017 to highlight constructivism and scaffolding, it was included in a multiplayer entertainment game that is currently available (although later versions may vary). *Hypatia* is a multiplayer open world primarily built for social entertainment. For the Alpha version of a high school-level chemistry lesson, the author served as a consultant to ensure best pedagogies were used in the module. The developers at the game company followed the mantra: “never break immersion”. But, learning scientists know it is also important to build in time for reflection so that students can create meaning around intense and novel stimuli.

The never-break-immersion guideline from entertainment may not migrate well into the education domain. In a cognitive, goal-driven learning situation, it may be efficacious to request learners remove the headset to make handwritten notes or to engage in face-to-face collaborations/question sessions with a partner. These are empirical questions. We do not yet have the answers.

In the *Hypatia* game world, players first create non-humanesque avatars by choosing from a library of body parts. This module described was called *Kapow Lake*; it was conceived of as a high school lesson using fireworks to instruct in physics and chemistry. Two learning goals were embedded: (1) understand which metal salts burst into which colors, and (2) understand the preliminary physics behind why the burst is perceived as a particular color. Players start on the beginner side of the lake, they can watch fireworks in the sky and are motivated to build some of their own.

One can scaffold cognitive elements, as well as interface one. As a form of UI (user interface) scaffolding, light cues, were used to "signpost" players to a certain building. In a sphere, it can be difficult to know where to travel next. With free exploration, precious classroom time could be wasted with students trying out dead-end options. Via the lit doorway, we encourage players to enter the expert's shed to learn more.

In order to construct their own fireworks, players must first master the names of the salt colors. The salts are grey, and names are not readily deducible from their exteriors. Players would grasp the triggers of the hand controls and when their avatar hands collided with a metal salt, the salt would be picked up. The first series of grey metal salts (see Fig. 5) did not have the colors on the labels. Thus, players did not know that the salt called strontium would burn red. Via guided exploration, they

Fig. 5 The strontium Bohr model. Note the wave heading towards the avatar's eye is a red wave

would place each salt into the flame of the Bunsen burner and note the color that the salt burned.

Figure 5 shows the avatar (Jessica) on the left side of the screenshot. The salt labels are now colored and visible (i.e., if strontium burns red, how will copper burn?). After Jessica places the grey salt over the flame a Bohr atom model of strontium appears on top of the flame.

Recall that the first profound affordance of VR is the immediate presence. Note that the screenshot is taken from the 3rd person POV for the purposes of edification, but Jessica, the human player, is seeing the atom floating towards her in 1st person or a “head on” POV. This is very engaging, indeed it could be alarming if it moved too quickly.

After she places the strontium over the heat, the outer electron jumps from the stable outer orbit. The unstable orbit is shown briefly as a dotted ring during play. Quickly, the electron falls back to its more stable orbit, as it does this a packet of energy called a photon is released. This photon is perceived in the red spectrum. In Fig. 5, the photon has been visualized as *both* a red wave and a particle heading towards the eye.[6] Jessica is watching the dynamic model in 3D and she perceives the photon as traveling directly into her eye. (This is perhaps the only thing humans want heading directly towards our eyes!) The sinusoidal movement was designed to be somewhat slow, so it would not be frightening.

The simulation of the photon as a wave reifies the concepts that energy is released by the heat burst, and that that the energy is then perceived by the human eye as a visible wavelength. The five other salts release electrons from different orbits, thus creating different wavelengths. Once players are able to match all six metal salts to their colors, the players are signposted to exit the back door to the multistaging firework building area.

This is where the social and collaborative aspects comes into play, because other experts are often out by the lake building multistage rockets and can give feedback and clap when the final version is correct. We scaffolded the difficulty of building the rocket. The player is first asked to build a one color firework. Then players are requested to make their rockets burst in a predetermined sequence of multiple colors. If a player is having trouble, someone else in the game can come over to help. When a rocket explodes correctly, there are often group shouts of approval. The building of the firework rocket is a sequential production. Using the hand controllers, a player must construct in a certain order: tube first, then fins, salts, fuse, then the cone top. After some minutes of free exploration, they are instructed to build specific multistage, color sequence rockets. This is an engaging task, but it also serves as a form of stealth assessment (Shute, 2011). Now a teacher, or spectator, can observe whether the student really understands how strontium and copper need to be sequenced to make a red *then* a blue explosion.

---

[6] In a small usability study, several players reported this model helped them to understand color perception. Whether the task inadvertently supports an incorrect model of “red waves moving through the air” could be explored with a larger and more formalized study. These sorts of issues are always a tension when visualizing abstract phenomena.

8 The Necessary Nine

As the technology moves forward, designers should keep principles of best practices in mind, and instructors should consult the principles when making purchasing decisions. The term "best" is relative. It depends on several constraints including the affordances of the technology—which are rapidly changing. The previous section describes the multiple embodied principles in detail. This chapter ends with the top contenders below. These are easier to recall, and if there are only resources to focus on a subset of the main guidelines, then the author recommends the *Necessary Nine*:

- Scaffold cognitive effort (and the interface)—one step at a time
- Use guided exploration
- Give immediate, actionable feedback
- Playtest often—with correct group
- Build in opportunities for reflection
- Use the hand controls for active, body-based learning
- Integrate gestures that map to the content to be learned
- Gestures are worth the time and extra expense—they promote learning, agency, and attenuate simulator sickness
- Embed gesture as a creative form of assessment, both during and after the lesson.

9 Conclusion

It is an exciting time for education and VR, filled with opportunity and enlivened by a rapidly changing hardware landscape. Besides issues around *how* to design optimal lessons, there are over-arching questions regarding *when* to insert a VR lesson. Aukstakalnis (2017) shares an anecdote about a student in a design class who regrets designing his first project in a VR headset during the year-long course because he missed watching his peers work in the real world. The student admitted that he "missed learning from his peers' collective mistakes" (p. 306). This is an instance of the timing being off; perhaps the digitized platform should have been made available after a real world introduction.

Clearly more research is needed on learning in VR, and the design guidelines presented here will be refined as the hardware and its affordances change. This chapter focused on the two profound affordances associated with the latest generation of VR for educational purposes: (1) *presence*, and (2) the *embodied affordances of gesture in a three-dimensional learning space*. VR headsets with hand controls allow for creative, kinesthetic manipulation of content, those types of movements and gestures have been shown to have positive effects on learning, and the controllers can be used for innovative types of assessment. A new graphic "cube" is introduced to help visualize the amount of embodiment in immersive educational lessons. It is our hope that the case studies and the set of design guidelines will help others to design optimal immersive VR lessons.

Acknowledgements Many thanks to James Comstock, Tyler Agte, Dennis Bonilla, the crew at TIMEFIREVR, and Diane Carlson. The 2D version of Natural Selection "Catch a Mimic Game" was funded by NSF grant number 1423655. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

References

Abrahamson, D. (2009). Embodied design: Constructing means for constructing meaning. *Educational Studies of Mathematics, 70,* 27–47. https://doi.org/10.1007/s10649-008-9137-1.

Abrahamson, D., & Trninic, D. (2015). Bringing forth mathematical concepts: signifying sensorimotor enactment in fields of promoted action. *ZDM Mathematics Education, 47*(295). https://doi.org/10.1007/s11858-014-0620-0.

Alaraj, A., Lemole, M. G., Finkle, J. H., Yudkowsky, R., Wallace, A., Luciano, C., et al. (2011). Virtual reality training in neurosurgery: Review of current status and future applications. *Surgical Neurology International, 2,* 52. https://doi.org/10.4103/2152-7806.80117.

Alibali, M. W., & Nathan, M. J. (2012). Embodiment in mathematics teaching and learning: Evidence from learners' and teachers' gestures. *Journal of the Learning Sciences, 21*(2), 247–286.

Aukstakalnis, S. (2017). *Practical Augmented Reality: A guide to the Technologies, Applications, and Human Factors for AR and VR*. Boston: Addison-Wesley.

Bailenson, J. N. (Producer). (2016, January 20, 2018). The Trials and Tribulations of Narrative in VR. *MediaX*. Retrieved from https://vhil.stanford.edu/news/2016/the-trials-and-tribulations-of-narrative-in-vr-mediax/.

Bailenson, J. N. (2017). *Experience on Demand: What Virtual Reality Is, How It Works, and What It Can Do*. New York, New York: W.W. Norton.

Bailenson, J. N., Patel, K., Nielsen, A., Bajscy, R., Jung, S., & Kurillo, G. (2008). The effect of interactivity on learning physical actions in virtual reality. *Media Psychology, 11*(3), 354–376.

Banakou, D., Hanumanthu, P. D., & Slater, M. (2016). Virtual embodiment of white people in a black virtual body leads to a sustained reduction in their implicit racial bias. *Frontiers in Human Neuroscience, 10*(601). http://doi.org/10.3389/fnhum.2016.00601.

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

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

Bjork, R. A. (1994). *Memory and metamemory considerations in the training of human beings Cambridge*. MA: MIT Press.

Bjork, R. A., & Linn, M. C. (2006). The science of learning and the learning of science: Introducing desirable difficulties. *Association of Psychological Science Observer, 19*(29), 39.

Black, J. B., Segal, A., Vitale, J., & Fadjo, C. L. (2012). Embodied cognition and enhancing learning and motivation. In D. Jonassen & S. Land (Eds.), *Theoretical foundations of learning environments*. NY: Routledge.

Broaders, S. C., Cook, S. W., Mitchell, Z., & Goldin-Meadow, S. (2007). Making children gesture brings out implicit knowledge and leads to learning. *Journal of Experimental Psychology: General, 136*(4), 539.

Cline, E. (2011). *Ready Player One*. New York, New York: Random House.

Congdon, E. L., Novack, M. A., Brooks, N., Hemani-Lopez, N., O'Keefe, L., & Goldin-Meadow, S. (2017). Better together: Simultaneous presentation of speech and gesture in math instruction supports generalization and retention. *Learning and instruction, 50,* 65–74.

Cook, S., & Goldin-Meadow, S. (2006). The Role of Gesture in Learning: Do Children Use Their Hands to Change Their Minds. *Journal of Cognition and Development, 7*(2), 211–232.

Craik, F., & Lockhart, R. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior, 11,* 671–684.

Dalgarno, B., & Lee, M. J. W. (2010). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology, 41*(1), 10–32. https://doi.org/10.1111/j.1467-8535.2009.01038.x.

Dede, C., & Richards, J. (2017). Glossary of realities' terms. In D. Liu, C. Dede, & J. Richards (Eds.), *Virtual, Augmented, and Mixed Realities in Education* (pp. 5–11). Berlin: Springer Verlag.

Dewey, J. (1966). *Democracy and education: An introduction to the philosophy of education*. New York: The Free Press.

Dunleavy, M. (2014). Design principles for augmented reality learning. *TechTrends, 58*(1), 28–34.

Engelkamp, J., & Zimmer, H. D. (1994). Motor similarity in subject-perfromed tasks. *Psychological Research-Psychologische Forschung, 57*(1), 47–53.

Freina, L., & Ott, M. (2015). *A Literature Review on Immersive Virtual Reality in Education: State Of The Art and Perspectives*.

Gibson, J. J. (1979). *The Ecological Approach to Visual Perception*. Boston, MA: Houghton Mifflin.

Glenberg, A. M. (2010). Embodiment as a unifying perspective for psychology. *Wiley Interdisciplinary Reviews: Cognitive Science, 1*(4), 586–596. https://doi.org/10.1002/wcs.55.

Glenberg, A. M., Witt, J. K., & Metcalfe, J. (2013). From the revolution to embodiment: 25 years of cognitive psychology. *Perspectives on Psychological Science, 8*(5), 573–585. https://doi.org/10.1177/1745691613498098.

Goldin-Meadow, S. (1997). When gestures and words speak differently. *Current Directions in Psychological Science, 6*(5), 138–143. https://doi.org/10.1111/1467-8721.ep10772905.

Goldin-Meadow, S. (2011). Learning through gesture. *WIREs. Cognitive Science, 2,* 595–607. https://doi.org/10.1002/wcs.132.

Goldin-Meadow, S. (2014). Widening the lens: What the manual modality reveals about learning, language and cognition. *Philosophical Transactions of the Royal Society, Biological Sciences, 369*(20130295). https://doi.org/10.1098/rstb.2013.0295.

Guiterrez, F., Pierce, J., Vergara, V., Coulter, R., Saland, L., Caudell, T. P., … Alverson, D. C. (2008). The effect of degree of immersion upon learning performance in virtual reality simulations for medical education. *Medicine Meets Virtual Reality 15: In Vivo, in Vitro, in Silico: Designing the Next in Medicine., 15*, 13.

Hasler, B. S., Spanlang, B., & Slater, M. (2017). Virtual race transformation reverses racial in-group bias. *PLoS ONE, 12*(4), 4.

Hostetter, A. B., & Alibali, M. W. (2008). Visible embodiment: Gestures as simulated action. *Psychonomic Bulletin & Review, 15,* 495–514.

Jang, S., Vitale, J., Jyung, R., & Black, J. (2016). Direct manipulation is better than passive viewing for learning anatomy in a three-dimensional virtual reality environment. *Computers & Education, 106*(March), 150–165. https://doi.org/10.1016/j.compedu.2016.12.009.

Johnson-Glenberg, M. C. (2017). Embodied education in mixed and mediated realities: Principles for content design. In D. Liu, C. Dede, & J. Richards (Eds.), *Virtual, Augmented, and Mixed Realities in Education* (pp. 193–218). Berlin: Springer Verlag.

Johnson-Glenberg, M. C. (2018). Immersive VR and education: Embodied design principles that include gesture and hand controls. *Frontiers in Robotics and AI, 5*(81). https://doi.org/10.3389/frobt.2018.00081.

Johnson-Glenberg, M. C., Birchfield, D., Koziupa, T., & Tolentino, L. (2014a). Collaborative embodied learning in mixed reality motion-capture environments: Two science studies. *Journal of Educational Psychology, 106*(1), 86–104. https://doi.org/10.1037/a0034008.

Johnson-Glenberg, M. C., Birchfield, D., Megowan-Romanowicz, M. C., & Snow, E. L. (2015). If the gear fits, spin it! Embodied education and in-game assessments. *International Journal of Gaming and Computer-based Simulations, 7*(7), 40–65. https://doi.org/10.4018/IJGCMS.2015100103.

Johnson-Glenberg, M. C., & Megowan-Romanowicz, M. C. (2017). Embodied science and mixed reality: How gesture and motion capture affect physics education. *Cognitive Research: Principles and Implications, 2*(24). https://doi.org/10.1186/s41235-017-0060-9.

Johnson-Glenberg, M. C., Megowan-Romanowicz, M. C., Birchfield, D., & Savio-Ramos, C. (2016). Effects of embodied learning and digital platform on the retention of physics content: Centripetal force. *Frontiers in Psychology, 7,* 1819. https://doi.org/10.3389/fpsyg.2016.01819.

Johnson-Glenberg, M. C., Savio-Ramos, C., & Henry, H. (2014b). Alien Health: A nutrition instruction exergame using the *Kinect* sensor. *Games for Health Journal: Research, Development, and Clinical Applications, 3*(4), 241–251. https://doi.org/10.1089/g4h.2013.0094.

Johnson-Glenberg, M. C., Savio-Ramos, C., Perkins, K. K., Moore, E. B., Lindgren, R., Clark, D., et al., Squire, K. (2014, June). *Science Sims and Games: Best Design Practices and Fave Flops.* Paper presented at the International Conference of the Learning Sciences (ICLS), Boulder, CO.

Johnson, D. W., & Johnson, H. (1991). *Learning together and alone: cooperation, competition, and individualization*. Englewood Cliffs, NJ: Prentice Hall.

Kalyuga, S. (2009). Managing cognitive load in adaptive ICT-based learning. *Journal of Systemics Cybernetics and Informatics, 7,* 16–21.

Kapur, M. (2016). Examining productive failure, productive success, unproductive failure, and unproductive success in learning. *Educational Psychologist, 51*(2), 289–299. https://doi.org/10.1080/00461520.2016.1155457.

Karpicke, J. D., & Roediger, H. L. (2008). The critical importance of retrieval for learning. *Science, 319*(5865), 966–968. https://doi.org/10.1126/science.1152408.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75–86. https://doi.org/10.1207/s15326985ep4102_1.

Kontra, C., Lyons, D., Fischer, S., & Beilock, S. L. (2015). Physical experience enhances science learning. *Psychological Science, 26*, 737–749. doi:10:1177: 0956797615569355.

Laviola, J. J., Kruijff, E., McMahan, R. P., Bowman, D. A., & Poupyrev, I. (2017). *3D User interfaces: Theory and Practice* (2nd ed.). Boston: Addison-Wesley.

Lindgren, R., & Johnson-Glenberg, M. C. (2013). Emboldened by embodiment: Six precepts regarding the future of embodied learning and mixed reality technologies. *Educational Researcher, 42*(8), 445–452. https://doi.org/10.3102/0013189X13511661.

Maister, L., Slater, M., Sanchez-Vives, M. V., & Tsakiris, M. (2015). Changing bodies changes minds: Owning another body affects social cognition. *Trends in Cognitive Sciences, 19*(1), 6–12. https://doi.org/10.1016/j.tics.2014.11.001.

Makransky, G., Lilleholt, L., & Aaby, A. (2017). Development and validation of the multimodal presence Scale for virtual reality environments: A confirmatory factor analysis and item response theory approach. *Computers in Human Behavior, 72*(C), 276–285. https://doi.org/10.1016/j.chb.2017.02.066.

Mayer, R. E. (2009). *Multimedia Learning* (2nd ed.). New York: Cambridge University Press.

Megowan, M. C. (2007). *Framing Discourse for Optimal Learning in Science and Mathematics.* (PhD), Arizona State University, Tempe, AZ.

Metcalfe, J. (2017). Learning from errors. *Annual Review of Psychology, 68*(1), 465–489. https://doi.org/10.1146/annurev-psych-010416-044022.

Mikropoulos, T. A., & Natsis, A. A. (2011). Educational virtual environments: A ten-year review of empirical research (1999–2009). *Computers & Education, 56*(3), 769–780. https://doi.org/10.1016/j.compedu.2010.10.020.

Minocha, S., Tudor, A., & Tilling, S. (2017). Affordances of mobile virtual reality and their role in learning and teaching. *Proceedings of British HCI, Digital Make Believe, 1*.

Mitchell, N., Cutting, C., & Sifakis, E. (2015). GRIDiron: an interactive authoring and cognitive training foundation for reconstructive plastic surgery procedures. *ACM Transactions on Graphics, 34*(4), 1–12. https://doi.org/10.1145/2766918.

Nathan, M. J., Walkington, C., Boncoddo, R., Pier, E. L., Williams, C. C., & Alibali, M. W. (2014). Actions speak louder with words: The roles of action and pedagogical language for grounding mathematical reasoning. *Learning and Instruction, 33*, 182–193. 10.1016.

Oculus. (2018). *Developers: Best Practices*. Retrieved from https://developer.oculus.com/design/latest/concepts/book-bp/.

Palinscar, A. S., & Brown, A. L. (1984). Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities. *Cognition and Instruction, 1*(2), 117–175. https://doi.org/10.1207/s1532690xci0102_1.

Pea, R. D. (2004). The social and technological dimensions of scaffolding and related theoretical concepts for learning, education, and human activity. *Journal of the Learning Sciences, 13*(3), 423–451. https://doi.org/10.1207/s15327809jls1303_6.

Piaget, J. (1997). *The language and thought of the child* (3rd ed.). London: Routledge.

Repetto, C., Pedroli, E., & Macedonia, M. (2017). Enrichment effects of gestures and pictures on abstract words in a second language. *Frontiers in Psychology, 8*(2136), 11. https://doi.org/10.3389/fpsyg.2017.02136.

Rizzo, A., Difede, J., Rothbaum, B. O., Reger, G., Spitalnick, J., Cukor, J., & Mclay, R. (2010). Early evaluation of the Virtual Iraq/Afghanistan exposure therapy system for combat-related PTSD. *ANNALS OF THE NEW YORK ACADEMY OF SCIENCES, 1208* (Psychiatric and Neurologic Aspects of War Development), 114–125.

Rosenshine, B., & Meister, C. (1994). Reciprocal teaching: A review of the research. *Review of Educational Research, 64*(4), 479–530. https://doi.org/10.3102/00346543064004479.

Salen, K., & Zimmerman, E. (2004). *Rules of play: Game design fundamentals*. Cambridge, MA: MIT Press.

Schaub, M., & Abadi, F. (2011). Integrated population models: A novel analysis framework for deeper insights into population dynamics. *Journal of Ornithology, 152*(1), 227–237. https://doi.org/10.1007/s10336-010-0632-7.

Schell, J. (2014). *The Art of Game Design* (2nd ed. Vol. New York): Taylor Francis.

Segal, A. (2011). *Do Gestural Interfaces Promote Thinking? Embodied Interaction: Congruent Gestures and Direct Touch Promote Performance in Math*. Dissertation, ERIC. ISBN: ISBN-978-1-1246-2610-9.

Segal, A., Black, J., & Tversky, B. (2010). Do Gestural Interfaces Promotoe Learning? Congruent Gestures Promote Performance in Math. Paper presented at the 51st Meeting of the Psychonomic Society Conference, St. Louis, Missouri.

Shute, V. (2008). Focus on formative feedback. *Review of Educational Research, 78*(1), 153–189. https://doi.org/10.3102/0034654307313795.

Shute, V. (2011). Stealth assessment in computer-based games to support leanring. *Computer Games and Instruction, 20,* 503–523.

Skulmowski, A., & Rey, G. D. (2018). Embodied learning: Introducing a taxonomy based on bodily engagement and task integration. *Cognitive Research, 3*(1), 6. https://doi.org/10.1186/s41235-018-0092-9.

Slater, M., & Sanchez-Vives, M. V. (2016). Enhancing our lives with Immersive virtual reality. *Frontiers in Robotics and AI, 3*(74). https://doi.org/10.3389/frobt.2016.00074.

Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments *Presence: Teleoperators and Virtual Environments, 6*, 603–616.

Snow, R. E., Corno, L., & Jackson, D. N. (Eds.). (1996). *Individual differences in affective and conative functions*. New York: Macmillan.

Squire, K. D. (2008). Video games and education: designing learning systems for an interactive age. *Educational Technology, 48*(2), 17–26.

Stanney, K. M., & Hash, P. (1998). Locus of user-Initiated control in virtual environments: Influences on cybersickness. *Presence: Teleoperators and virtual environments, 7*(5), 447–459. https://doi.org/10.1162/105474698565848.

Varela, F., Thompson, E., & Rosch, E. (1991). *The embodied mind: Cognitive science and human experience*. Cambridge, MA: MIT Press.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: The Harvard University Press.

Waldrop, M. M. (2015). Why we are teaching science wrong, and how to make it right. *Nature News, 523*(7560), 272–275. https://doi.org/10.1038/523272a.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review, 9*(4), 625–636.

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments, 7*(3), 225–240.

Woolfolk, A. (2007). *Educational psychology* (10th ed.). Boston: Pearson.

Chapter 6
A Broad View of Wearables as Learning Technologies: Current and Emerging Applications

Victor R. Lee and R. Benjamin Shapiro

1 Introduction

Over the last decade, wearable technology has been generating increasing attention from educational technologists. At a base level, wearables offer a new form of mobile technology by freeing hands from carrying a handheld device. Smartwatches and fitness tracker bands are perhaps the most iconic of wearables, although many features included in such devices represent incremental steps forward from what has already been available in handhelds and other existing technologies. In light of that, the buzz around wearables may seem to be a letdown; they are little more than a new and unnecessary electronic toy for those who can afford to buy them. To that view, wearables will likely generate initial interest and then quickly fall out of favor (for example, consider the rise and fall of the asymmetrically designed Google Glass wearable camera and head-mounted display system). It comes as little surprise that there are skeptics who wonder aloud whether wearables and their enthusiasts will have much to offer to the future of education (Carr-Chellman, 2015, p. 19).

Ultimately, the uptake and impact of wearables in service of teaching and learning remain to be seen. However, our orienting position for this chapter is that the most effective forms and uses of wearable technologies for both formal and informal learning settings are still being developed and explored. Educational technologists should first recognize that wearables are not monolithic as a set of technology that will either succeed or fail for educational purposes. There is a diversity in devices and forms of technology integration and user experience. Smartwatches and fitness

---

V. R. Lee (✉)
Department of Instructional Technology and Learning Sciences, Utah State University, Logan, USA
e-mail: victor.lee@usu.edu

R. B. Shapiro
Department of Computer Science, ATLAS Institute, University of Colorado Boulder, Boulder, USA
e-mail: ben.shapiro@colorado.edu

P. Díaz et al. (eds.), *Learning in a Digital World*, Smart Computing and Intelligence, https://doi.org/10.1007/978-981-13-8265-9_6

trackers are just a subset of what is both available and possible. As with all educational technologies, the effectiveness and worthiness of wearables will ultimately depend on a multitude of social and human factors and vary from one setting to the next. Thus, in this chapter, a central argument is that the future questions asked by educational technologists about wearable technologies should be explicit about how those wearable technologies are intended to be used, and how those intended uses are supportive of specific forms of teaching and learning.

The chapter is provided primarily as a survey of some current and emerging applications of wearable technologies for both formal and informal learning environments. In the sections that follow, we describe examples of teaching and learning activities that incorporate wearable technology organized by the types of support that they provide in the learning environment. For instance, one of the support types we describe below relates to personal expression, and the examples therein examine how some wearables are used as a motivating and expressive context that can also provide encounters with engineering and design. The list of supports are not mutually exclusive of one another, nor do we view particular types of devices as being restricted to a single form of support. For instance, a wearable activity tracker could be made useful in a physical education class to help students reach certain health goals or help students to monitor and keep their heart rates in specific ranges. It could also be made useful in an electrical engineering class as an object to take apart and then rebuild for a predetermined use case. The wearable activity tracker is rather neutral with respect to how it is used. While certain functionalities are more prominent in a given technology or a given wearable platform, the onus is on educational technologists to conceive of and develop ways that the technology can be used. The educational technologist's role is to define how to support the attainment of some learning goals in a way that is considerate of the needs of a given setting.

In addition to describing some of the work that others are doing in related areas such as human-computer interaction, educational technology, and learning sciences, we will provide two more detailed accounts of wearable technologies that, as used in the manner we propose, support the collection and examination of records of bodily experience. These receive more detail in part because they are our own projects, and thus we have direct knowledge of challenges, needs, and opportunities. However, we also believe that the ability to obtain and ask questions about records of bodily experience is an especially promising direction for wearable technology design and research for learning that has not been as prominent in the extant literature. The two examples are intentionally divergent in the types of technologies that are used (off-the-shelf devices vs. custom-made) and whose bodily experience is being examined. This is done in order to show the breadth of possibility when one pursues this direction of design and research.

2 Compelling Qualities of Wearable Technology

Broadly speaking, the category of "wearable technology" can extend to any designed object that is worn by the body, such as clothing, jewelry, protective gear, or performance improving equipment. In considering the advantages wearables have, we have considered the different roles that wearable objects have played in the past and continue to play in various societies and cultural practices (Eicher & Evenson, 2014). However, we recognize that in current times, when one hears "wearables" and "wearable technology", the common inference is that there is some form of digital augmentation in the form of a microprocessor or circuitry integrated into the wearable. Digital technology-enhanced wearables will be discussed in the sections below.

There are three qualities of wearables that make them compelling as an emerging technology. First, wearables do not necessarily need to be actively held with one's hands. To be worn is to be carried on the body in some manner. This allows for the digital technology embedded in a wearable to remain present on a person for hours or days without requiring attention. Wearables can "tag along" while we do other things, making it possible for someone to focus on completing difficult jumps and turns on their skateboard and rely on their GoPro camera to catch a record of the sick moves that were completed. This redistributes what forms of work are being done by various individuals and technologies in the system. Other examples of this redistribution include the ability to compute location on a GPS watch without a user having to reference maps, stars, or signs around them while on a hike, or to know how many flights of stairs were climbed during the day without paying conscious attention to moments of ascension and keeping a tally.

A second compelling quality of wearables is their relationship with presentation and disclosure. Several wearables are visible and are made part of our public appearance. This allows others to make inferences, some of which we attempt to engineer in how we design our public appearance. Take for example how wristwatches can serve to present an individual as athletic (a sport watch), academic (a calculator watch), oriented toward outdoors activities (a Garmin GPS watch), or to communicate wealth (a designer watch). For fitness tracking, the gold standard of step counting has been hip-worn devices that can detect motion from foot impact with the ground. However, wrist-based wearables have become far more popular and taken on a variety of different styles as the wrist is more visible, making the wearable a conversation starter, and a way to communicate something about one's values, interests, and resources. On the other hand, wearables can also be discrete. They can hide from view and still be present by keeping their size small or by integrating them into other objects that are already worn. For instance, discreet devices now exist on the market that are worn on one's waist to help track breathing patterns and posture (e.g., *Lumo Lift*, *Spire*, etc.). Individuals with Type 1 diabetes may wear a continuous glucose monitor that attaches to their skin and fits underneath their shirt so that their status as a diabetic is not immediately visible (e.g., Lee, Thurston, & Thurston, 2017). The amount of flexibility designers have with respect to form factor creates opportunities that have yet to be fully explored.

Finally, wearables can serve as extensions of self. Taking the example of a person with Type 1 diabetes, a wearable glucose monitor acts as an important replacement for a part of the body that does not work normally. Other major medical devices that are necessary for continued survival that must be worn or attached to one's body impact the sense of personal identity that patients experience, with some seeing themselves as part machine or a form of cyborg (e.g., Raia et al., 2014). This also extends to medical devices that are not essential for survival, but can change quality of life, such as hearing aids. Some individuals also seek to go beyond technology that can be worn and instead voluntarily implant technology, such as magnets or sensors, under their skin to alter and explore what their bodies can perceive (Heffernan, Vetere, & Chang, 2016). Those individuals appear to sense and know the world in new ways because of the augmentations and modifications that are on (or in) their bodies. These may appear rather dramatic as examples, but they do raise questions about where are the boundaries of one's self. Others, particularly in cognitive science, have posed similar questions about where the human and their mind begins or ends (Clark, 2008), with one of the most famous examples being a blind man sensing the world around him with a walking stick (Bateson, 1971):

> Consider a blind man with a stick. Where does the blind man's self begin? At the tip of the stick? At the handle of the stick? Or at some point halfway up the stick? These questions are nonsense because the stick is a pathway along which differences are transmitted under transformation, so that to draw a delimiting line across this pathway is to cut off a part of the systemic circuit which determines the blind man's locomotion. (p. 445)

A fundamental point made in this oft-cited example by Bateson (and also made thoughtfully by others, such as Hutchins (1995)) is that the unit that is the thinking human is not as clear cut as would be suggested by the boundary of our skin. Considering wearable technology, this question of boundaries can be further blurred partly because the technology can be always there and, in the examples discussed thus far, take on more essential roles in various tasks. Granted, it may still be a while before wearables consistently do the critical work in various learning environments as providing life support,[1] but it represents a possible direction in which we may be heading. It is a different way of thinking about technology that has been typically afforded a desktop computer or handheld mobile device. More work remains to be done, but in the examples of how wearables are being used in learning environments that follow, strands of these qualities of wearables—their ability to be always present, their flexible presentation and disclosure, and their connection to self—appear in what various research and design teams have been engineering and studying.

---

[1] Although, it is worth noting that worn body cameras in law enforcement are beginning to play increasingly important roles in shaping public opinion about differing accounts of citizen-officer encounters, driving community activism, and serving as evidence in high stakes court cases, all of which are sites where learning still takes place.

3 Forms of Support Provided by Wearables in Education

In this section, we provide a survey of uses and projects involving wearables in formal and informal education settings, organized by types of support that we have identified. The list is not exhaustive. Rather, it is intended to help articulate some common themes that are appearing in educational technology-related fields.

3.1 Wearable Technology to Support Personal Expression

Wearables can build upon the ability to be a form of public display. This has been one way in which electronic textiles, or e-textiles, have been used in educational settings.

Although often presented as an important strand of the Maker movement in education, a number of recent and current e-textiles projects allow for students to build their own wearables by creating clothing items, badges, and other accessories that are enhanced with electronic and digital components. At a minimum, a simple electronic textile project could involve a coin cell battery, wire, and an LED. What often makes electronic textiles unique and amenable to wearability has been the integration of "high" and "low" technology and the use of conductive thread in place of wire. This mixes the "softer" medium of cloth and fabric with the "hard" silicon of microcontroller boards and metal wires of actuators.

A compiled volume on electronic textile projects, *Textile Messages* (Buechley, Peppler, Eisenberg, & Kafai, 2013), documents a number of examples and applications of electronic textiles that range from custom and interactive handbags to hats to sweatshirts that double as turn signals (see Leah Buechley's Turn Signal Biking Jacket[2]). One of the recognized potentials of electronic textiles is that it challenges western gendered views of various cultural practices, such as computing and sewing. Searle & Kafai (2015a) has documented how the use of electronic textiles can serve as a bridge for engaging in new practices that students may not otherwise explore because of dominant gender norms. For instance, in their work with adolescent youth, Searle & Kafai observed that many young men expressed the greatest pride in their increased sewing ability when working with e-textiles while young women found pathways into computing. Introductory electronic textiles experiences, often involving starter wearable projects such as the creation of light-up bracelets and electronically-enhanced t-shirts, have shown documented learning gains in disciplinary content (e.g., Tofel-Grehl et al., 2017). Circuitry knowledge has been shown to increase from multi-week engagement with e-textile projects involving wearables (Peppler & Glosson, 2013), as has introductory knowledge related to computing and craft production (Lee & Fields, 2017).

Besides providing youth with new visions of how technology can be infused into different media, electronic textiles provide a platform for personal expression. Kafai, Fields, & Searle (2014) have documented how aesthetic considerations in the design

---

[2] https://www.instructables.com/id/turn-signal-biking-jacket/.

of electronic textiles can be a critical driver in pushing for new learning. In their case studies, the desire to make a textile project have a certain look led to exploration and discovery of new techniques and considerations in circuit design. Electronic textiles are also an appealing medium through which cultural knowledge can be valued and expressed. Culturally relevant projects have sought to connect students to community and family-based craft knowledge and also found ways in which personal interests within mainstream youth culture can be expressed through custom-made e-textile wearables (Searle & Kafai, 2015b). This allows for expressing values and history within an indigenous community or even affinity for a professional sports team.

This particular manner of deploying wearable technology tends to privilege youth agency and voice and follow with the constructionist paradigm of creating a public artifact while developing new understandings. While making wearable e-textiles can be time consuming, they have so far been well-sustained in educational technology research through supportive out-of-school (Peppler & Glosson, 2012) and classroom-based (Buechley, Eisenberg, & Elumeze, 2007) curriculum, portfolio platforms (Peppler, Maltese, Keune, Chang, & Regalla, 2015), and community support websites (e.g., instructables.com).

3.2 Wearable Technology to Integrate Digital Information into Social Interactions

The digital technology incorporated in wearables fundamentally involves manipulations, transformations, and transmissions of information. Commercially, this may take the form of a smartwatch that converts barometric pressure changes into numerical values and transmits that information via Bluetooth to smartphone. In educational settings, other forms of information transmission, largely emphasizing peer-to-peer interactions, have been appearing. These information exchanges add and integrate new layers for social interaction.

Smart badges have been among the most classic instantiations for storing and transmitting information during face-to-face social interactions. An early example developed out of MIT was a modification of the typical plastic-encased, paper-printed conference badge that states the name and affiliation of academic conference attendees. The new form of wearable technology badge, dubbed the “Thinking Tag”, was worn by conference participants who went to different stations to answer multiple choice questions to share their opinions on some topic (Borovoy, McDonald, Martin, & Resnick, 1996). For instance, a pre-planned question asked with whom of a list of pre-selected celebrities would you most want to have dinner or which of three major concerns about the future of the internet do you feel was the most urgent. When a conference attendee stood across from another attendee, a different number of LEDs on the badge would light up to indicate how many answer responses they had in common. The underlying idea in this activity was to encourage and facilitate conversations by making information (i.e., responses to a common set of questions) more public and easily exchanged. Learning about one another would then take place through these augmented conversations.

This model of “smart badges” that are worn during face-to-face interaction have been extended to support participatory simulations in classrooms, especially with respect to learning related to complex systems content. For instance, Klopfer, Yoon, and Rivas (2004) provided students with modified Thinking Tag badges to enact two forms of complex systems simulation activities with middle and high schools. One system modeled the spread of disease in which one student’s tag was “infected” with a virus, and their face-to-face interactions with other students in the class created a risk of spreading the infection. Ultimately, students can see from their own interactions how quickly diseases can spread and experience the logistics curve typically used to model disease spread. This form of activity also generated questions about what factors impacted the immunity of the population (i.e., the entire class of students) and individuals within the system (i.e., specific students and the badges that they wore). The other system described by Klopfer et al., used Thinking Tags to help students learn about Mendelian genetics. Each badge encoded a set of traits and interactions with other students wearing badges yielded different organism outcomes related to survival. The students could use their experiences interacting with other students to state what benefits were associated with what traits and how they were modeled in the badge simulation.

A more recent badge-based participatory simulation project involved students using badges and their interactions with one another as simulating the network structure of the early Internet (Brady, Orton, Weintrop, Anton, Rodriguez & Wilensky, 2017). Students’ badges were categorized as network endpoints, data packets, and routers. During the simulation, the “data packets” interacted with various “routers” whose badges provided partial destination address information that help direct the data packet badge wearers to other “routers” until they reach their intended “endpoint”. Through the simulation, the students saw how different strategies of sending data packets impacted the number of nodes needed to efficiently send information. They also encountered physical instantiations of network terms such as “bandwidth” and “congestion” as they existed within that network architecture, particularly as student queues formed at different routers since only one pair of badges could interact with one another at a time.

More developed instantiations of these simulation and information transmission projects through wearables remain to be completed. The novel use of wearables for learning purposes capitalized on the ability of wearables to remain present on the wearer and mediate information exchanges that could ultimately lead to new forms of learning interactions. In these examples, the wearables were “piggyback riding” on face-to-face interactions. This created a new potential information layer that supported new ways for learners to both engage with complex ideas and to spark new conversations.

3.3 Wearable Technology to Support Educative Role-Play

Custom wearables can support learners in trying out different roles than the ones they normally occupy when they are made highly visible and connect to some other referenced entity or world. To some extent, this was suggested by some of the previously mentioned examples involving e-textiles, where students could express affiliation to specific communities, and participatory simulations, where students could be infectors or pretend to be anthropomorphized data packets. However, educative role-play touches upon, but does not necessarily occupy the exact same design space. For role-play, the wearable technology is intended to preserve some form of fidelity to another person or living thing and encourage the wearer of that technology to behave in a manner comparable to that which is being publicly signaled by that wearable item.

An example of a participatory simulation in which role-play is involved is the *BioSim* environment (Thompson, Danish, & Peppler, 2017) that encourages young children to use custom hand puppets that look like bees and wearable indoor location tracking technology as they forage for nectar and pollinate large "plants" located around the classroom. The goal of this design is to help students learn both structure and function relationships between bees and plants as well as complex systems relationships in bee colonies. The use of the bee puppet encourages students to enact the bee role within the simulation and promotes specific forms of engagement and interaction among students (e.g., bees cannot verbally communicate with one another using words, and the bees' body movements are thought to be a form of communication). The bee puppet also cues students into thinking about how to engage with artifacts in the room (i.e., large flowers that are part of the simulation). Instead of leveraging their human abilities, students move and communicate with one another using the affordances of the bee body and simulated bee brain. Notably, it is not the case that humans' capabilities are strictly greater than bees: while humans have spoken language and bees do not, bees can fly while humans cannot. Students in BioSim role-play bee by emulating a communicative bee dance with their puppets and "flying" around the room. This role-play supports careful consideration of how bees communicate and interact with one another and their environments in ways that are sharply different than humans' capabilities.

Another animalistic wearable role-play approach has been demonstrated in Leilah Lyons and her colleagues' work with the *A Mile in My Paws* interactive climate change zoo exhibit (2015). The intention of this exhibit was to help patrons better understand the impact of climate change on various animal species. In her use of wearable technology, she and her design team created an experience where patrons role-played polar bears. The patrons wore large weighted bear gloves that had been equipped with accelerometers so that the gloves could detect motion and transmit that information to a live display reporting calorie expenditure and distance traveled. The humans role-playing as polar bears were then tasked with foraging for a preferred food source (i.e., seals) located on sea ice. The exhibit then presented various scenarios using actual data and satellite imagery from the years 1975, 2010, and forecasted data for 2045 as rising global temperatures cause more sea ice to melt. These different scenarios and the requirement to paddle in the heavy gloves helped demonstrate the extra survival pressures that are placed on polar bears as the amount of sea ice decreases and more water appears between icy regions. By paddling their glove-covered arms, the zoo visitors experienced an embodied sense of how much harder a polar bear must work in order to work to survive under changing environmental conditions.

A Mile in My Paws and *BioSim* are both wearable-supported role-play activities focused on understanding animal biology and ecology, but they addressed different aims using different types of wearables. *A Mile* is primarily about empathy cultivation, achieved by immersing humans in a life-or-death task of progressively escalating impossibility. The wearable affords a narrative experience wherein the fun of strapping on a pair of bear gloves and frolicking across the arctic changes to one where the bear is struggling to survive in an environment inundated by life-threatening changes precipitated by climate change. By identifying as the bear, learners feel the consequences of a shrinking polar environment. Yet the actual abilities of the bear body make little impact on the experience. In principle, another animal could be used in the simulation, or even a simulated human who must seek food and shelter in response to scarcity caused by climate change. In contrast, *BioSim*'s task structures are deeply shaped by the abilities of bees: the conceptual learning goals of the activity are intimately shaped by the abilities of the bee body and bee brain, as are the range of allowable student actions to accomplish those goals. The student experience is designed to emphasize the contradistinctive work of accomplishing communication and movement in ways that are disjoint from human capabilities. This distinction is revisited in another example below.

3.4 Wearable Technology for Just-In-Time Notification in Complex Learning Environments

Many people who use a consumer wearable are familiar with notifications and reminders that are communicated by the device. For example, when an appointment is upcoming or a text has been received or the wearer has been sitting for too long, a smartwatch will often buzz and show that information to notify the wearer immediately, with the underlying assumption being that the user wants that information and will respond at the time of notification. While personal experience suggests that there is more work to be done (as some reminders can be frustrating and undesired, although Afergan, Hincks, Shibata, & Jacob (2015) offer one compelling alternative), the potential use cases, especially for classroom teachers who must continually respond to and notice important events in complex settings, are now being developed. This connects to the potential of wearable technology to alter our sensing processes and our general awareness of the environment.

One example of this for teachers, following from the model of smartwatch notification, has been discussed by Quintana, Quintana, Madeira, & Slotta (2016). In the computer-supported collaborative learning literature, "orchestration" has increasingly been used to describe the facilitation work that must be done within and across collaborative learning activities (Dillenbourg & Fischer, 2007). A classroom teacher might need to coordinate the use of various software tools for students, immediately encourage specific kinds of classroom discourse with just-in-time prompting, announce and direct transition between learning activities, and adapt planned activities in response to what she believes is appropriate for the students at a given moment. While one promising model for supporting this is to help teachers develop more robust knowledge for pedagogical practice and to enhance their ability to notice critical classroom events (Sherin, Jacobs, & Phillipp, 2010), wearables and their notification capabilities could help to redistribute some of the cognitive work that is involved in orchestration. In Quintana et al. work, Apple Watches were explored as a tool to provide notifications at timed intervals to remind teachers keep track of lesson flow relative to allotted time (e.g., asking the teacher if there are any groups ready to present to the class, reminding them that ¾ of the class period has passed and a synthesis discussion should take place, etc.) and to send notifications of student progress to the teacher (e.g., a student group had just submitted some documents to a common digital workspace or another student group has not appeared to make any posts to a common digital knowledge sharing space). In initial focus group responses, teachers appeared to find a wearable device-based notification system preferable to a handheld notification as they could be more discrete in obtaining the notification (i.e., not draw attention from students as the teacher looked at a phone) and could provide teachers with an ongoing sense of how students in the class were doing if they had to dedicate more attention to one subset of students on that day.

An alternative notification-based approach was recently proposed with mixed-reality smart glasses in classrooms that use intelligent tutoring systems (ITS) (Holstein, Hong, Tegene, McLaren, & Aleven, 2018). Here, the idea is to overlay icons and images over the teacher's eyeglass-view of students and workstations. This could then provide a form of real-time augmented reality analytics related to student progress and mastery within the ITS, according to the ITS metrics. Other views through these smart glasses could provide "deep dives" with specific students when the teacher gazes at a specific workstation with a student seated at it. The wearable display would then show the teacher what immediate challenge problems a student is encountering on their workstation screen and a brief history of their performance on similar problems in the ITS. Such information could enable the teacher to be better equipped to provide student assistance and spend less time diagnosing where a student is having difficulty.

A comparable system using mixed-reality eyewear has been attempted in a university setting (Zarraonandia, Aedo, Diazm & Montero, 2013), in which clicker response systems that allow for students in large lectures to provide projected feedback to the instructor about their level of understanding of lectured content can instead be transmitted directly to the instructor's worn display system. While that approach can be a form of private, just-in-time notification to the instructor to adjust her information delivery without disrupting her lecture, it is worth noting that it could deprive students of the sense that their struggles and concerns with the classroom instruction are more widely shared, as can be made visible in more traditional classroom response system configurations where classroom poll results are projected for all to see. However, all of these examples provide a glimpse of how teachers, in particular, can be provided with information in new ways through wearables and have their abilities to notice classroom sentiment and events in new ways.

4 Wearables to Obtain Records of Bodily Experience

Having surveyed some of the manners of support that wearables provide in various educational projects, we now turn to one other form of support that has been the focus of some of our own projects. This form of support is to enable learners to examine records of bodily activity that are obtained from wearable devices. In some respects, this connects to growing interest in embodied cognition as it relates to learning technologies (Lee, 2015). The underlying assumption for embodied learning technologies is that some knowledge of bodies—tacit or explicit—can play a critical role in the development of new understandings. For example, moving arms at different rates and constructing new sensorimotor schema may help students develop new intuitions of rational number (Howison, Trninic, Reinholz, & Abrahamson, 2011), stepping in certain directions to think about numerical order may support better understandings of the number line (Fischer, Link, Cress, Nuerk, & Moeller, 2015), and forming geometric shapes with the body on a large field (Hall, Ma, & Nemirovksy, 2015) or on a computer screen may help in the learning of geometry (Nathan & Walkington, 2017).

For wearables, we are interested in what we already know about what bodies do and encounter in routine activities. We know, for instance, that a day is typically filled with standing, walking, and sitting. We also may know more specifics about when those activities take place. While we may not know that information exhaustively, it may be that we know enough to begin to ask questions and inspect records of routine behavior in a way that makes routine bodily experience into a novel inquiry. Furthermore, our understanding of bodily experience need not be restricted to simply our own bodies. It can relate to other people, or to other organisms as well. In the examples that follow, we present one project (led by Lee) that involves students examining school day movement using more conventional off-the-shelf technology. In the other (led by Shapiro), learners are using pets as their focus and drawing upon what they know and care about with respect to their animal companions to develop ways to obtain records of animal sensory data and to examine that data in order to gain more insight into how pets experience the world.

4.1 Inspecting Routine School Day Activities with Commercial Activity Trackers

For several years, Lee has been involved in a multi-year design-based research project involving fifth and sixth grade classrooms to develop new activities for learning elementary statistics content such as variability, distribution, measures of center, and comparing across data samples. This project, referred to as the *Physical Activity Data Project*, involved the use of commercial technologies such as high speed cameras and fitness trackers that have included heart rate monitors, hip-based step counters, and wrist-based activity trackers in its most recent iteration. The guiding assumption was that these off-the-shelf technologies could be re-purposed in classrooms to build upon students' knowledge of their own activities and the automatically obtained records of those activities to devise ways to bootstrap understanding of statistical ideas such as outliers and central tendency. For instance, students may know when they had an unusual pattern of activity due to a field trip or class assembly and be able to thoughtfully consider if data collected from such a day should be considered an outlier and what effect its inclusion would have on the rest of a week's worth of movement data.

The typical classroom arrangement involved issuing a wearable activity tracker (e.g., *Fitbit Flex* device worn around the wrist) to every student in the classroom to wear throughout the school day. Data from these devices were automatically transmitted to anonymous online accounts and then accessed using a custom web tool developed by the project team that could obtain subsets of data from one or more students depending on the query being made. For instance, the class may have wanted to compare the number of steps taken per minute during PE on a given day from all students in the class so that they could compare the activities of the boys and girls in class.

Some of the infrastructure, besides several dozen Fitbit devices, is further described in Lee, Drake, & Thayne (2016) and summarized here. First, computers already in the classroom were converted into covert antenna stations so that data could be obtained from several activity tracker devices passively throughout the day. Data from the devices were stored by Fitbit and reported back to users as total values or in 15-min increments because their primary users are assumed to be adults with smartphones and working professionals whose schedules conform to those increments. However, school schedules must be very resourceful with respect to instructional time, and may have recess scheduled at a seemingly specific time such as 10:12–10:27 AM. That required us to extract data by the minute with a data grabber tool. Additionally, the raw data was a long table of numbers that could be made more dynamic through visualization software (i.e., *TinkerPlots* data visualization software) (Konold & Miller, 2005). Once those data were presented in a visualized form, they were projected so that students could develop narratives about their activity data, raise concerns about what did and did not get captured by a wearable device, and pose questions that could then be used as investigations for themselves or for

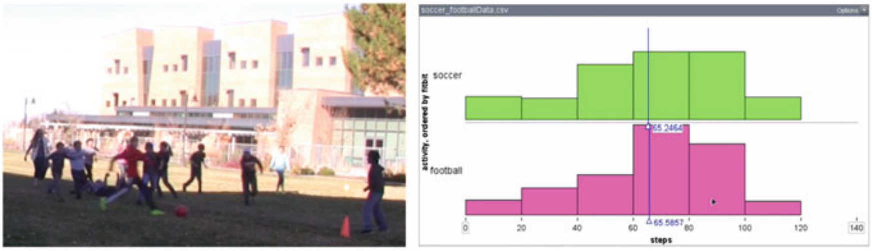


Fig. 1 Students playing soccer at a participating school and the resultant data from the entire class that were extracted, cleaned, and analyzed by a student group that wanted to see if soccer (top) and (American) football (bottom) had meaningful differences

the entire class to pursue. Depending on the activity, they would access their own individual data or collections of class data.

Recess was a time we discovered as especially exciting for students to explore, as the students had more knowledge about the activities of recess than their teachers and could provide testimony to what they and their friends had done. This would produce disagreements among students that could be reconciled by examination of their activity tracker data. As an example (Fig. 1), in one fifth grade class, students who examined data about their school day activity had noticed that their most active minute (based on the number of steps taken) came from a morning recess when that student and his friends were playing (American) football. That led to animated student posturing where a group of male students claimed football was the toughest game because of that single data point. For students who felt differently and who also believed that the football students were relying on too little data, they devised a data investigation where they extracted data of classmates playing both football and playing soccer on two days and organized those data into a histogram. They filtered out students who they recalled being non-participants and times when the gameplay had not actually started even though it was part of recess (i.e., setting up the field) given their review of data points. They then found that the overall shape of the distributions was largely the same and the mean values were nearly identical, leading them to conclude that despite what the basketball boys had thought, soccer and football at recess for their class were equally demanding activities. The rivalry between playgroups motivated statistical investigation and comparison, and firsthand experience with data collection supported the exclusion of data points in the analysis (data cleaning).

A second example comes from a sixth grade class at a different school where discussions of students' recess data, as obtained by Fitbit devices and represented in *TinkerPlots*, yielded questions about whether students who were using the jump rope at recess had their jumps count as steps on the devices. After extensive classroom discussion of how they could evaluate that, as the wearable devices issued to them did not provide a numerical display for them to check immediately, the students devised an experiment where different groups of students would primarily walk or jump rope

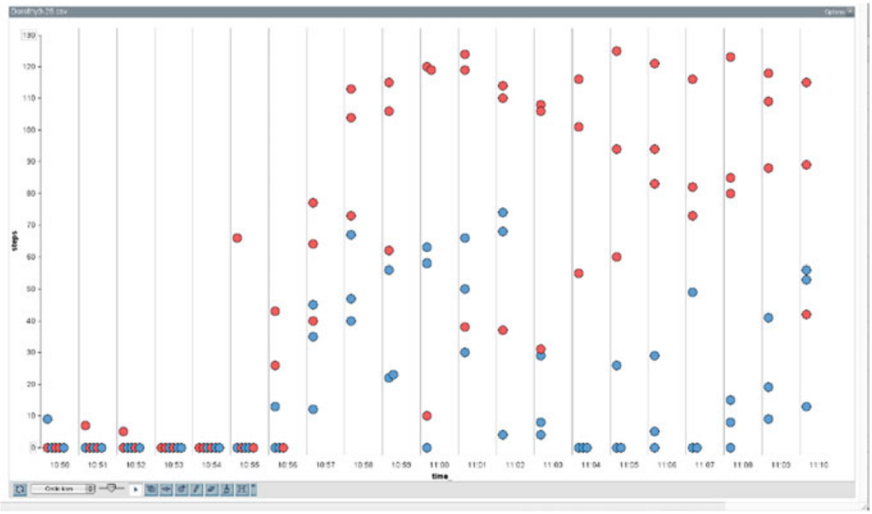


Fig. 2 Data from students during a designed walk (topmost points) and jump rope (bottom most points) comparison experiment to determine if jumping was counted as steps by a Fitbit activity tracker. The students realized upon examining the data and peer discussion that jumping involved a great deal of stationary time and they would need to design a new experiment that eliminated the stationary time

during recess and compare the values (Fig. 2). However, upon inspection of the data the next day, they found that while there tended to be less steps taken by those who jumped rope, they were unable to tell if jumping was registered as a step by the device because there were several minutes when jump ropers stood and waited for their turns to jump. Furthermore, the jump ropers walked to reposition themselves in preparation of their jumps and to get out of the way and return to line after completing their turns. This came about when students began to debate what these records of their recess showed and why, and ultimately led to a new experimental design (Drake, Cain, & Lee, 2017). From this, the students were engaging in thoughtful reflection of data and how to design experiments that could produce data to support conclusions in response to questions they were asking.

The *Physical Activity Data Project* has yielded encouraging findings with respect to how a unit that involves these wearables and accompanying lessons fare against traditional elementary statistics units taught in these same classrooms (Lee & Thomas, 2011; Lee, Drake, Thayne, 2016). The use of commercial wearables created a durable, quantified, shareable, and partially contestable record of school day experience. (e.g., whether jump rope gets recorded validly). The examination of these records of their bodily experiences then led to new learning interactions that would have been difficult to engineer without the use of the wearables.

4.2 Intersubjective Sensation Wearables with Pets

The *BioSim* and *Walk a Mile in My Paws* examples presented above illustrate ways in which role-play using wearables can support biology education. In *Walk a Mile*, awareness of the impossibility of polar bears' survival is generated through empathetic perspective taking (e.g., starving to death while role-playing as a beleaguered polar bear). In *BioSim*, role-play consists of limiting one's use of innate human abilities (spoken language) while pretending to enact actions that exceed human capabilities (flying). We conceive of the role-play in *BioSim* as a sort of intersubjective action: humans studying bees learn by acting in Bee-like ways. This intersubjectivity primarily lives in the role-play, for which the wearables primarily function as props. Nothing about them fundamentally constrains human action to its bee-like capabilities; nor do the wearables actually enable people to fly.

Recently, Shapiro and collaborators Mike Eisenberg, Joe Polman, Annie Kelly, Christine Chang, Chris Hill, and Nicholas Gonyea have begun their *Pet Project*, an effort to investigate how wearables for *intersubjective sensation* can support scientific investigation and engineering by young people and their families. Within the project team's own homes, the sensory worlds of pets are frequent subjects of discussion (e.g., *What is the dog hearing?*), an observation that motivated the investigators to wonder about how such curiosities could motivate young people's scientific inquiry into animal sensation. The basic premise of the project is that young people will design and conduct scientific experiments, complemented by reading of scientific literature, to develop answers to questions that they have about pets' sensory capabilities (e.g., *Do dogs see color?*). These answers will, in turn, be used to parameterize customizable wearables that can be used by humans to step into the sensory worlds of animals by producing records of animals' bodily experiences. This, in turn, is intended to catalyze further inquiry.

For example, a group of young people interested in the topic of dog color perception might attempt to train their dogs to respond differently to different color cues, eventually noticing that their pets cannot reliably distinguish red from green, but can distinguish yellow from blue. The reason for this is that dogs' eyes have a different set of color receptors in their eyes (functional for yellow and blue) than those contained in human eyes (which detect red, green, and blue).

Having discovered the scientific fact of dogs' dichromatic color perception, students might then wonder *What's it like to have dog vision?* At that point, they might don augmented reality "goggles" created by the *Pet Project* team. These goggles consist of a low-cost Google Cardboard plus an augmented reality app capable of rendering a real-time camera video feed into a customized video output (e.g., using a dog vision function to transform the colors and sharpness of the input into dog-like color and acuity). Here, records of *animal* experience are created. Generalized, this approach can support Doggy Vision, Cat Vision, Bee Vision, or any other re-rendering of the visual field desired, given suitable input devices. The team has already developed a prototype Doggy Vision mobile app (for Android and iOS), which it has recently begun using to design and pilot learning experiences.

Fig. 3 (left) View of bucks from Shapiro's dining room and (**b**) (right) same photo rendered with dog color sensitivity and acuity

When using Doggy Vision, it is strikingly and immediately apparent how different dog vision is to human vision. The importance of these differences rapidly becomes apparent when investigating *why* dogs sometimes seem to behave in peculiar ways. Shapiro's dogs, for example, ignore bucks lounging behind his house, but immediately freak out when those animals begin to move. One explanation for this may be that they cannot see unmoving deer against a background of green grass; this explanation is well-supported by Fig. 3a, b.

In addition to designing wearables for visual remediation, the *Pet Project* team has working prototypes for ultrasonic hearing and for wearable whiskers. We note that these technologies offer possibilities for intersubjective sensory augmentation that categorically exceed what Doggy Vision can support. Whereas dog vision is strictly less powerful than human vision, dogs, cats, and many other creatures can perceive sound far outside of the human hearing range. Similarly, many animals' whiskers (or similar features) are far more mechanically sensitive than human whiskers; some are capable of electrostatic sensing in addition to mechanical detection. Wearables that emulate these sensory capabilities offer the potential for young people to actually hear or feel the world in the ways that animals do (e.g., to notice sounds that they would otherwise be deaf to), and therefore transcend beyond the sort of role-play props that the wearables in projects like *BioSim* are. They provide records of animal experience that some learners did not realize were ever present in the first place.

Though still early in its course, we believe that the *Pet Project* approach of wearables for remediating experience of the world through intersubjective sensation offers enormous potential for science education that is situated in practices of empathy and perspective taking. It leverages interest and curiosity about our animal companions and produces records of animals' bodily experiences that can be inspected and compared to already familiar human sensory experience.

5 Summary and Future Directions

This chapter has presented a survey of recent, current, and emerging uses of wearable technologies for education. It has proposed a characterization of how wearables can be made supportive that can build upon existing ubiquitous wearables (e.g., smartwatches) or involve newly imagined use cases and models for teaching and learning. We have articulated some of the specific features of wearable technology that are appealing for educational technologists, knowing that more will be identified in the future by others. Of special interest to us has been how wearable technology can be used to represent records of bodily experience. The examples we discussed in depth (i.e., some of our own projects with wearables, including the *Physical Activity Data Project* and the *Pets Project*) were provided to illustrate the breadth of the potential design space.

As some of the most amplified voices in society that espouse the benefits of wearable technology are highly technocentric and do not always recognize the complexities of education and the needs of learners, it is appropriate to be skeptical of claims that any given wearable technology represent singular solutions to challenges we face as educational technologists. However, educational technologists should still remain open to the many different ways that wearables are being deployed currently. We also should remain receptive to the premise that wearables can remediate relations between learners, content matter, practices, and ultimately learning experiences in powerful ways. Our recommendation for those who write about wearable technology in education in the future is that they carefully consider the sociotechnical system that is involved and make explicit in their arguments about wearable technology how they envision a wearable technology will support teaching and learning. We have introduced some language in this chapter, in the forms of a simple classification and articulation of educative supports that could be used by others. These include descriptions of the support offered by wearables in terms of personal expression, integration of social interactions, role-play, supporting notifications, and inspection of bodily records.

As technology continues its onward march toward portability and ubiquity, coupled with the presence of more researcher and technologist voices that will inevitably propose wildly different new ideas for how wearables could be used for educational purposes, we expect to see exciting new developments. For example, e-textiles are evolving such that they are increasingly supporting new display capabilities and interactive behaviors (Devendorf et al., 2016). New research is underway that is making notification systems commonly found on commercial wearables smarter with respect to how and when they alert a user (Afergan et al., 2015). New physiological measures (such as electrodermal activity, which is now detected by some wearable technology products—see Cain & Lee (2016) for one example) have the potential to increase the situational awareness of wearable technology to make future devices even more supportive of complex learning activities at the most desirable times.

Furthermore, we close with the observation that as far as wearable technology is concerned, there are important loci of innovation that we should be monitoring and where partnerships should be developed. Take as an example cosplay culture as an extension of educative role-play. At comic book and gaming conventions, it is common to see individuals of all ages and gender identities dressing as characters from fictional universes. For instance, one might dress as Sailor Moon or Iron Man and walk through a convention floor striking iconic poses, reciting famous lines, re-enacting fight scenes, as well as posing for pictures with other guests. Cosplayers often build their own costumes, which involves substantial mathematical reasoning as patterns and measurements must be customized to build a new outfit, mask, or accessory. Moreover, technology is encountered when lights and other effects are integrated into the costume, as could be done when creating a light-up version of the arc reactor for the Iron Man suit example mentioned above or in the creation of a LED-enhanced cyberpunk outfit for a cosplay event (Bender & Samson, 2015). Cosplay in itself also represents a form of literacy practice in which characters and premises from established fictional universes are remixed into new narratives that are enacted through our bodies (Knobel & Lankshear, 2007). Thus, this use of wearable technology creates new opportunities for a number of content areas and competences to be enacted, that can range from mathematics, engineering, and the humanities. Similar directions could be pursued with performing arts and rave communities, where innovations in costuming and clothing are continually being made in order to attract attention, express aesthetic appreciation, or even protect wearers of the technology from predatory behavior (Letourneau et al., 2018). Beyond looking at traditional educational settings, technologists would be best served by also looking at other communities where innovations in wearables are also appearing.

The future of wearables in education remains to be determined. It may be that wearables will not find an enduring place in the larger educational ecosystem (Carr-Chellman, 2015). However, that is not a foregone conclusion. Educational technologists currently have the opportunity to articulate what kinds of wearable technologies show the greatest promise. It is our view that we now have the opportunity to be imaginative in our endeavors—by either conceiving of entirely new technologies or new uses for existing technologies. At the same time, it is important that we be grounded in our design rationales. As researchers and designers, we should state how a wearable will be supportive of specific educational aims. Thus far, some promising examples we have summarized in this chapter suggest the field of educational technology may be beginning to take steps in those directions.

Acknowledgements This work reported in this chapter was supported by funding from the US National Science Foundation under Grants No. DRL-1054280 and IIS-1736051. The opinions expressed herein are those of the authors and do not necessarily reflect those of the National Science Foundation.

References

Afergan, D., Hincks, S. W., Shibata, T., & Jacob, R. J. (2015). Phylter: A system for modulating notifications in wearables using physiological sensing. In *International Conference on Augmented Cognition* (pp. 167–177). Springer, Cham.

Bateson, G. (1971). The cybernetics of "self": A theory of alcoholism. *Psychiatry, 34*(1), 1–18.

Bender, S., & Samson, K. (2015). *Re-crafting mathematics: Early lessons learned at the intersection of textile crafts and math*. Paper presented at Fablearn 2015, Stanford, CA.

Borovoy, R., McDonald, M., Martin, F., & Resnick, M. (1996). Things that blink: Computationally augmented name tags. *IBM Systems Journal, 35*(3.4), 488–495.

Brady, C., Orton, K., Weintrop, D., Anton, G., Rodriguez, S., & Wilensky, U. (2017). All roads lead to computing: Making, participatory simulations, and social computing as pathways to computer science. *IEEE Transactions on Education, 60*(1), 59–66. https://doi.org/10.1109/TE.2016.2622680.

Buechley, L., Eisenberg, M., & Elumeze, N. (2007). Towards a curriculum for electronic textiles in the high school classroom. In *Proceedings of the Conference on Innovation and Technology in Computer Science Education (ITiCSE)* (pp. 28–32). Dundee, Scotland.

Buechley, L., Peppler, K., Eisenberg, M., & Kafai, Y. (Eds.). (2013). *Textile messages: Dispatches from the world of e-textiles and education*. New York, NY: Peter Lang Publishing.

Cain, R., & Lee, V. R. (2016). Measuring electrodermal activity to capture engagement in an afterschool maker program. In P. Blikstein, M. Berland, & D. A. Fields (Eds.), *Proceedings of FabLearn 2016: 6th Annual Conference on Creativity and Making in Education* (pp. 78–81). Stanford, CA: ACM.

Carr-Chellman, A. (2015). The future of "our" field. *TechTrends, 59*(4), 18–21.

Clark, A. (2008). *Supersizing the mind: Embodiment, action, and cognitive extension*. Oxford University Press.

Devendorf, L., Lo, J., Howell, N., Lee, J. L., Gong, N.-W., Karagozler, M. E., … Ryokai, K. (2016). *"I don't want to wear a screen": Probing perceptions of and possibilities for dynamic displays on clothing*. Paper presented at the Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, San Jose, California, USA.

Dillenbourg, P., & Fischer, F. (2007). Computer-supported collaborative learning: The basics. *Zeitschrift für Berufs-und Wirtschaftspädagogik, 21,* 111–130.

Drake, J., Cain, R., & Lee, V. R. (2017). From wearing to wondering: Treating wearable activity trackers as tools for inquiry. In I. Levin & D. Tsybulsky (Eds.), *Optimizing STEM education with advanced ICTs and simulations* (pp. 1–29). Hershey, PA: IGI Global.

Eicher, J. B., & Evenson, S. L. (2014). *The visible self: Global perspectives on dress, culture and society*. New York, NY: Fairchild Books.

Fischer, U., Link, T., Cress, U., Nuerk, H.-C., & Moeller, K. (2015). Math with the dance mat: On the benefits of embodied numerical training approaches In V. R. Lee (Ed.), *Learning technologies and the body: Integration and implementation in formal and informal learning environments* (pp. 149–163). New York, NY: Routledge.

Hall, R., Ma, J. Y., & Nemirovsky, R. (2015). Re-scaling bodies in/as representational instruments in GPS drawing. In V. R. Lee (Ed.), *Learning technologies and the body: Integration and implementation in formal and informal learning environments* (pp. 112–131). New York, NY: Routledge.

Heffernan, K. J., Vetere, F., & Chang, S. (2016). You put what, where?: Hobbyist use of insertable devices. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. Santa Clara, California, USA: ACM.

Holstein, K., Hong, G., Tegene, M., McLaren, B. M., & Aleven, V. (2018). *The classroom as a dashboard: co-designing wearable cognitive augmentation for K-12 teachers*. Paper presented at the Proceedings of the 8th International Conference on Learning Analytics and Knowledge, Sydney, New South Wales, Australia.

Howison, M., Trninic, D., Reinholz, D., & Abrahamson, D. (2011). The mathematical imagery trainer: From embodied interaction to conceptual learning. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 1989–1998). Vancouver, BC, Canada: ACM.

Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.

Kafai, Y., Fields, D., & Searle, K. (2014). Electronic textiles as disruptive designs: Supporting and challenging maker activities in schools. *Harvard Educational Review, 84*(4), 532–556. https://doi.org/10.17763/haer.84.4.46m7372370214783.

Klopfer, E., Yoon, S., & Rivas, L. (2004). Comparative analysis of Palm and wearable computers for participatory simulations. *Journal of Computer Assisted learning, 20*(5), 347–359. https://doi.org/10.1111/j.1365-2729.2004.00094.x.

Knobel, M., & Lankshear, C. (2007). *A new literacies samples*. New York, NY: Peter Lang.

Konold, C., & Miller, C. (2005). *TinkerPlots: Dynamic data exploration: Statistics software for middle school curricula.* Emeryville, CA: Key Curriculum Press.

Letourneau, N., Khalifa, A., Gorczynski, M., Gomes, C., Smith, R., Paluskiewicz, S., … Confrey-Maloney, T. (2018). *Wearable apparatus for detecting a target substance in a liquid*. U.S. Patent Application No. 10/016,315.

Lee, V., Thurston, T., & Thurston, C. (2017). A comparison of discovered regularities in blood glucose readings across two data collection approaches used with a type 1 diabetic youth. *Methods of Information in Medicine, 56*(open), e84–e92. https://doi.org/10.3414/me16-02-0047.

Lee, V. R. (Ed.). (2015). *Learning technologies and the body: Integration and implementation in formal and informal learning environments*. New York, NY: Routledge.

Lee, V. R., Drake, J. R., & Thayne, J. L. (2016). Appropriating quantified self technologies to improve elementary statistical teaching and learning. *IEEE Transactions on Learning Technologies, 9*(4), 354–365. https://doi.org/10.1109/TLT.2016.2597142.

Lee, V. R., & Fields, D. A. (2017). A rubric for describing competences in the areas of circuitry, computation, and crafting after a course using e-textiles. *International Journal of Information and Learning Technology, 34*(5), 372–384.

Lee, V. R., & Thomas, J. M. (2011). Integrating physical activity data technologies into elementary school classrooms. *Educational Technology Research and Development, 59*(6), 865–884. https://doi.org/10.1007/s11423-011-9210-9.

Lyons, L. (2015). Exhibiting data: Using body-as-interface designs to engage visitors with data visualizations In V. R. Lee (Ed.), *Learning technologies and the body: Integration and implementation in formal and informal learning environments* (pp. 185–200). New York, NY: Routledge.

Nathan, M. J., & Walkington, C. (2017). Grounded and embodied mathematical cognition: Promoting mathematical insight and proof using action and language. *Cognitive Research: Principles and Implications, 2*(1), 9. https://doi.org/10.1186/s41235-016-0040-5.

Peppler, K., & Glosson, D. (2013). Stitching circuits: Learning about circuitry through e-textile materials. *Journal of Science Education and Technology, 22*(5), 751–763. https://doi.org/10.1007/s10956-012-9428-2.

Peppler, K., Maltese, A., Keune, A., Chang, S., Regalla, L. (2015). The MakerEd open portfolio project: Survey of makerspaces, Part II. In: S. Chang, A. Keune, K. Peppler, & L. Regalla (Eds.), Open portfolios: Maker education initiative research brief series (pp. 47–53). http://makered.org/wp-content/uploads/2015/03/Open-Portfolio-Project-Research-Brief-Series_FULL_final-small.pdf.

Quintana, R., Quintana, C., Madeira, C., & Slotta, J. D. (2016). Keeping watch: Exploring wearable technology designs for K-12 teachers. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (pp. 2272–2278).

Raia, F., Cadeiras, M., Nsair, A., Cruz, D., Ramos, G., Alvarenga, C., … Deng, M. C. (2014). Science, technology, body and personhood: The concept of health emerging in high-tech modern medicine practice. In J. L. Polman, E. A. Kyza, D. K. O'Neill, I. Tabak, W. R. Penuel, A. S. Jurow, K. O'Connor, T. Lee, & L. D'Amico (Eds.), *Learning and becoming in practice: The International Conference of the Learning Sciences (ICLS) 2014* (Vol. 2, pp. 1012–1016). Boulder, CO: ISLS.

Searle, K. A., & Kafai, Y. B. (2015a). Boys' needlework: Understanding gendered and indigenous perspectives on computing and crafting with electronic textiles. In *Proceedings of the Eleventh Annual International Conference on International Computing Education Research*. Omaha, Nebraska, USA.

Searle, K. A., & Kafai, Y. B. (2015b). Culturally responsive making with American Indian girls: Bridging the identity gap in crafting and computing with electronic textiles. In *Proceedings of the Third Conference on GenderIT*. Philadelphia, PA, USA.

Sherin, M. G., Jacobs, V. R., & Phillipp, R. A. (Eds.). (2010). *Mathematics teacher noticing: Seeing through teachers' eyes*. New York, NY: Routledge.

Thompson, N., Peppler, K., & Danish, J. (2017). Designing BioSim: Playfully encouraging systems thinking in young children. In Z. Robert & K. G. Michael (Eds.), *Handbook of research on serious games for educational applications* (pp. 149–167). Hershey, PA, USA: IGI Global.

Tofel-Grehl, C., Fields, D., Searle, K., Maahs-Fladung, C., Feldon, D., Gu, G., & Sun, C. (2017). Electrifying engagement in middle school science class: improving student interest through e-textiles. *Journal of Science Education and Technology, 26*(4), 406–417. https://doi.org/10.1007/s10956-017-9688-y.

Zarraonandia, T., Aedo, I., Díaz, P., & Montero, A. (2013). An augmented lecture feedback system to support learner and teacher communication. *British Journal of Educational Technology, 44*(4), 616–628. https://doi.org/10.1111/bjet.12047.

Chapter 7
Promoting Online Learning Community with Identity Transparency

Na Sun, Mary Beth Rosson and John M. Carroll

1 Introduction

With advances in technology and broadened access to educational resources, university degree programs provided via online delivery have drawn considerable attention and effort, and have been rewarded with regular increases in enrollment (Kena et al., 2015) and comparable achievements in terms of learning outcomes (Shachar & Neumann, 2003). However, distance education continues to suffer from the mere fact of distance: separation of instructors and students in terms of time and space leads to feelings of being socially removed from the situation (Guo, Tan, & Cheung, 2010). This social isolation is a major contributor to the retention problems common in online education (Carr, 2000; Tinto, 1975). Ashar and Skenes (1993) suggest that learning goals attract adults to an online program, but it is the presence of a social environment that makes them persist.

At the same time, productive social interaction is an important component of collaborative learning (Clegg et al., 2013); being part of a learning community leads to

---

N. Sun (✉)
College of Information Sciences and Technology, Pennsylvania State University,
332 Info Science and Tech, E363 Westgate Building, University Park, PA 16802, USA
e-mail: nzs162@psu.edu
URL: http://personal.psu.edu/nzs162/

M. B. Rosson
College of Information Sciences and Technology, Pennsylvania State University,
332 Info Science and Tech, E397F Westgate Building, University Park, PA 16802, USA
e-mail: mrosson@psu.edu
URL: http://mrosson.ist.psu.edu

J. M. Carroll
College of Information Sciences and Technology, Pennsylvania State University,
332 Info Science and Tech, E319 Westgate Building, University Park, PA 16802, USA
e-mail: jcarroll@ist.psu.edu
URL: http://jcarroll.ist.psu.edu

P. Díaz et al. (eds.), *Learning in a Digital World*, Smart Computing
and Intelligence, https://doi.org/10.1007/978-981-13-8265-9_7

fuller engagement with the class and dialogue (D. J. Brown et al., 2011). Not surprisingly, social presence and social interaction are predictors of students' learning performance in CSCL (Xing, Kim, & Goggins, 2015). For example, online learners with higher social belonging also report better learning outcomes (Kizilcec & Halawa, 2015). Furthermore, learners with higher social skills exhibit greater social interaction, which in turn mediates the impact of system functionality on learning (Xing et al., 2015). These suggest the importance of fostering communities for online learners despite the physical distance between students and teachers, or among learners themselves.

The remainder of this chapter is organized as follows: Sect. 2 will discuss recent literature about communities in online learning environment. Several empirical studies situated in degree-earning online program will then be illustrated in Sect. 3, including one interview study with instructors teaching online courses (Sun & Rosson, 2017), one interview study with students actively enrolled in online degree programs (under review), and a survey study with a larger sample of online learners (Sun, Rosson, & Carroll, 2018). We conclude with a short summary and discuss design implication for similar online learning environments to promote community in Sect. 4.

2 Related Works

Although many studies of learning technologies have considered effects on building community (Borge & Goggins, 2014; Goggins, Laffey, & Gallagher, 2011), most of this work has situated community as feelings among classmates (Du, Rosson, & Carroll, 2012). Even learning-at-scale researchers (e.g., MOOCs) rely on the scoping of an online class to assess impacts of the online technology design on community. As one example, synchronous chat was offered as part of a MOOC, but this particular technology appeared to have no effect on forum participation or sense of community (Coetzee, Fox, Hearst, & Hartmann, 2014).

Education is offered online not only course by course, but also program by program. Limiting studies of online community to individual classes fails to account for repeated encounters, and for more longitudinal effects observable only through individual learners' trajectories through an education program. In addition, class-based discourse lasts for only one course, whereas computer-mediated interpersonal connections would typically emerge over longer periods of time (Walther, 2002). For instance, researchers have found that growth in social capital accumulated across online courses and leads to higher GPAs (Gašević, Zouaq, & Janzen, 2013). As Stahl and his colleagues point out in their theory of group cognition (Stahl, 2011), "*cooperative work involves a tight and complex integration of work at the individual, small-group and community levels*". Indeed, individual learning does not take place until it is situated in dyads or group (Vygotsky, 1980); meanwhile, such group-level interaction is also embedded in larger social structures, such as class, college, and university. This view of cooperative work suggests a need for careful examination of the social structures through which learning takes place; this need is especially strong for online learning, where the ways in which peers interact is radically different from traditional brick and mortar classrooms and schools. Thus, we seek to contribute to this fuller understanding of online learning community, namely one that *includes*, but also *goes beyond* a singular class.

Researchers investigating the nature and impacts of social behaviors in CSCL have studied students' communication artifacts (Ferschke et al., 2015) and activity logs (Soller, Wiebe, & Lesgold, 2002). For example, discussion posts and chat interactions are often used to enact social behaviors, such as lurking (Mustafaraj & Bu, 2015) and peer support (Appiah-Kubi & Rowland, 2016). To some extent, however, studies of discourse capture only part of the collaboration in an online environment, because the analysis of utterances ignores the larger social context within which a specific interaction takes place. To complement these findings, we present two qualitative studies (Sun & Rosson, 2017; Sun, Wang, & Rosson, 2019) and one quantitative study (Sun et al., 2018) that investigate students' and instructors' need and practices in building connections online on top of early research of students' perceptions (Appiah-Kubi & Rowland, 2016; Haythornthwaite, Kazmer, Robins, & Shoemaker, 2000; Shelley, 2008; Williams, 2015) and instructors' observations (R. E. Brown, 2001; Koh, Barbour, & Hill, 2010; Mcelrath & Mcdowell, 2008).

3 Case Studies in Degree-Earning Online Learning Environment

We introduce two interview studies in a computer-supported online learning environment for i-school classes. Following that, we share what we learned from a large-scale survey distributed to students enrolled online degree programs from 15 different disciplines, such as Information Sciences and Technology, Liberal Art and Business.

3.1 Instructors' Views of Community in an Online Degree Program

The main goal of the instructor interview study was to investigate whether and how distance education instructors see evidence of community amongst their students (Sun & Rosson, 2017). We started with the experiences and views of teachers because they are central agents in orchestrating online collaborative learning experiences. Accordingly, we grounded the study on the following questions:

1. What sorts of social connections do instructors perceive among their distance learners?
2. What techniques do online instructors use to promote such connections among students?

3. What implications do such findings have for design—both of online pedagogy and technology support?

3.1.1 Participants

We interviewed 11 instructors in the spring of 2016; all teach both in residence and online at the College of Information Sciences and Technology, Pennsylvania State University (PSU), with a range of prior teaching experience. Eight are American; two are from outside the United States. Five are females. The courses taught online by these instructors mirror what they teach in residence; our organization within the college has an interdisciplinary education mission, so the courses intermix a wide range of disciplines related to the information sciences, including computer programming, application and database design, security policies and laws, and enterprise architecture. Most of the online courses were for undergraduates; a few instructors teach both graduate (e.g., professional masters) and undergraduate courses.

3.1.2 Interview Protocol and Analysis

We began each interview with questions about prior teaching experience (e.g., courses, class size, how long online). We next asked for general reflections about connections among online students in three different social contexts: (a) among students in the class; (b) between the students and the instructor; and (c) with PSU. We focused primarily on online teaching, but at the end asked for a comparison of online and residential teaching. In the process of gathering data, instructors often interleaved comments about their own connections to students with those that the students have with each other, without explicitly placing themselves as "outsiders" to the student milieu; this is not surprising given that we were asking for personal impressions. Therefore, there is considerable overlap in the first two contexts with respect to the presence of communities. However, perceived connections at the level of PSU or the overall distance education program were viewed as more distinct; these connections are inherently more abstract, diffuse and to a great extent invisible. We also inquired about strategies and technology being used; student data they can access or would like to access; comparison between online and residential instruction; and visions or suggestions to improve sense of community. We interviewed 10 instructors in person; the other participated via a Google Hangout video call. We recorded 9.6 h of audio data, with an average of 52 min per interview session.

We first used open coding to obtain categories related to our research questions. The first author organized these codes into a table that consisted of code names, code memos defining the codes, and sample quotes. We asked a researcher outside the project to review this table using the method of constant comparison (Hallberg, 2006). Coding issues were resolved by discussion with the first author, with changes to categories as needed. The first and second authors then searched for semantic themes and examined similarities and differences, followed by a pruning of codes seen as irrelevant to the central issue of social connections. We organized the remaining high-level themes—indicators of perceived connections and techniques to foster connection—into a thematic map. Each theme was articulated into the subthemes that form our primary findings.

3.1.3 Research Findings

All instructors reported a wide range of "evidence" for the existence of social connections among students. In the discussion of their comments, we focus primarily on positive examples, as these help to paint a broad picture of what instructors notice about how their student interact with each other. Above all, community was seen as most perceivable in students' ***real-time engagement*** during class-wide live sessions where a majority of class members attend and participate in online chat. Instructors also reported that students' real-time engagement with one another could enrich the live sessions held as part of a course, because their shared discussion might uncover some hidden knowledge gap that instructors would not otherwise know to address. The result is a benefit for a broader audience that includes not only the witnesses, but also the students who may not have been there but viewed the recorded session later. One instructor who successfully attracted a large audience to her regular live sessions told us that she felt students' attachment to the class at the end of the semester, in that they were reluctant to end their semester together: "I have students that say: 'It's Tuesday night and there's no class, I really looked forward to class'. There was real camaraderie… I think they really bonded. I think there are some good connections that… some good networking connections that have been made." In addition, instructors found evidence of community or camaraderie in requests of continued collaboration with someone else in the class, and observed interaction in forum where peer learners root for stressful student who wrote a self-deprecating post: "A lot of people were rooting for him, 'I think you'll do good, I hope you'll get a lot out of this degree.'" Also, some instructors told stories of being invited to serve as a ***student club*** advisor and witnessed posts in Reddit (a popular public online forum) that reflected a strong sense of institutional pride.

In addition, instructors shared techniques that facilitate social connections in online classes. Among the most common methods, ***public introductions*** are often used to increase the visibility of peers' information and yield meaning social interaction in terms of group-formation. Some instructors also ***publicize bits of student assignment*** and use it as fuel to generate class' attention and discussion. They also used live sessions to show their teaching presence and ***the real and personal*** part about themselves. Another instructor further customized ***personalized communication*** to individual students to indicate his care and nurture connections with them.

3.2 Students' Bonds in an Online Degree Program

Similar to the instructor interviews, the main goal of the student interviews was to explore online learners' feelings of connection among peers. Specifically, we asked them to reflect on connections they may have experienced in different settings, ranging from relationships within small groups, to an entire class, and even beyond individual classes, at the level of a university.

3.2.1 Participants

We recruited 15 participants by distributing emails to online classes of an i-school based on the following criteria: (1) students with relatively more online course experiences, so as to obtain richer insights; and (2) diversity in demographic background and employment status. All participants resided in the U.S. at the time of the study, though some were traveling internationally while taking an online course. Most of our participants were 3rd year undergraduates or above, and had taken courses both within and outside of the i-school program; some were completing degrees in other departments while pursuing a secondary degree in the i-School. This allowed us to ask more generally about PSU distance courses (including Math, Economics, Political Science, Foreign language, Nursing, Communication, Human Development, Astronomy, Landscape Architecture). In this sense, although students were drawn from a small set of (seven) course rolls, their online learning experiences were much broader than these specific courses.

As intended, the participants represented a broad mix of age, ethnicity, life stages, and industry experience (Merriam, 2002). The majority of the participants (11 out of 15) were White, two Hispanic or Latino, one Asian and one African American; the median age was 34 and five were female. A majority (13) had transferred credits from other institutions (e.g., community college), with ten already having obtained (2-year) associate degrees. On average, participants had taken 15.25 courses. Their work experiences covered a wide range from internship to more than 20 years in IT: 10 had full-time jobs at the time of the interview; one was self-employed, 2 part-time, one in an internship, and two job-hunting. Through the screening activity, we were able to construct a sample that contained rich variations of attributes such as age, gender, ethnicity, career stage, location, and family status.

3.2.2 Interview Protocol and Analysis

Our semi-structured interviews were conducted remotely using video communication tools such as Skype or Google Hangout. At the beginning of the interview, we asked participants to reflect on their online education experiences with respect to PSU courses and programs. More specifically, we asked about academic, career and social goals. We then probed in depth the students' experiences and felt connections with peers in the context of three contrasting scopes: project groups, classmates, and the PSU virtual campus as a whole.

On average, the interviews lasted 61 min. The recordings were transcribed and examined through inductive thematic analysis (Braun & Clarke, 2006; Strauss & Corbin, 1998). Specifically, we first used open coding to obtain categories in the first few interview sessions and organized these codes into a table of codes, memos defining the codes, and sample quotes. Next, we searched for semantic themes and examined similarities and differences, followed by a pruning of codes seen as irrelevant to our research questions. We applied axial coding to the remaining high-level themes to identify categories and relations among them. Finally, each theme was mapped into the sub-themes that form our primary findings.

3.2.3 Research Findings

Our findings shed light upon how the different scopes we specified for thinking about relationships affected the connections that are sought or experienced; how students use technology to interact with instructors and each other; and the strategies they use to build connections with online peers. Across the three scopes, students felt strongest connections with group members, calling them "***almost friends***," thinking that they might have become "really good friends" if it were not for the challenges of distance and the cost of managing relationships after the end of a course project. They also valued relationship that developed over time, and cited ***time zones*** as a key factor for choosing their own group members for the convenience of regular collaboration and working together. In particular, time zones are useful in indicating ***alignment of dedicated study time***; when these alignments do not match, there may be unequal contributions to collaborative work, sometimes even leading to resentment. Class-interaction or at least ***repeated name encounters*** in live text-based sessions and forum participation also lead to ***accumulated familiarity*** and feelings of connection. The feelings of connection can be stronger when they suffer through similar problematic situations, such as a teacher who simply disappears. In contrast, students felt connected with their virtual campus peers across PSU because of feelings of ***shared mission*** and ***shared organizational identity***.

Technically speaking, students created ***persistent online space*** outside of the Course Management System Portal provided by the University. In terms of communication, they use instant CMC tools such as GroupMe, Google Hangout or Skype; in terms of collaboration, they used Google Docs and GitHub to share and work on the same artifact. The immediacy of team support is often realized through such external tools for the sake of constant availability for close collaboration. Our participants appreciated the ***immediate interaction*** when it is available for online classes, such as live sessions or video-conferencing, even if they visit something that was pre-recorded. The immediacy of the interaction added personal flavors, for example through in situ life stories. Regarding the Course Management System provided by PSU, students reported poor social experiences primarily due to the ***cluttered interface*** in the mobile browsers and ***lack of instant messaging*** support related to communication services. Strategically, students often establish common ground with peers by writing and reading introductory posts inside the class forum. They also picked up their ***shared personal identity*** to achieve mutual understanding and support. Such shared identities cover a wide span of possible ways, including gender, work experience or career goals, academic goals, and life situations (e.g., parental status). Students often manage expectations through early communication, catch up with repeated encounters or prior group members, and lighten the tone of their conversations with social talk at the beginning of a regular meeting.

3.3 Quantifying Community Perception Among Online Students

In this study, we developed an self-report survey to characterize community understandings and value from the perspective of online students (Sun et al., 2018). Our longer term goal was to create and validate several contrasting measures of community feeling that could be used by us and other online learning community researchers.

3.3.1 Participants

We distributed the survey to all currently enrolled students in PSU's online education programs (i.e., World Campus programs, about 12 K students). We obtained usable responses from 740 online students; 59.9% were males, and 95.8% of them live in the U.S. (37.4% live in the same state as the host university). At an average age of 35.54 years old (SD = 10.25), participants are enrolled across 15 colleges, with a majority from the three whose programs are most available in World Campus (Liberal Arts 21.9%; Business 12.1%; IT 17.4%). Nearly half are pursuing bachelor degrees (47.2%), followed closely by those in master programs. 26.1% of them report being members of the World Campus student club. 62.9% of the respondents have never visited the host university in person. 82.7% of participants currently work for a company, 14.6% are not employed, 7% are self-employed (some as a second source of income).

3.3.2 Research Design

We present our analysis in two phases. First, we developed a set of robust constructs to use in assessing (1) Sense of Community (SOC, 10 items; based on previous empirical analysis of community scales by (Peterson, Speer, & McMillan, 2008; Rovai, Wighting, & Lucking, 2004); and (2) Community Collective Efficacy (CCE, 24 items developed by us) for the community domain of online learning. Second, we examined differences that might have resulted from the Virtual Campus Commu-

Table 1 Two definitions of community and two community constructs

	Sense of community	Community collective efficacy
VCC (n = 367) (*"all students currently enrolled in any World Campus degree program"*)	1. I can get what I need in the World Campus community 2. The community helps me fulfill my needs 3. I feel that I can rely on others in World Campus 4. I feel like a member of World Campus 5. I belong in the World Campus community. 6. I feel that I matter to other World Campus students 7. I feel connected to World Campus community 8. I have a good bond with others in this community 9. I have friends at World Campus to whom I can tell anything 10. I feel close to others at World Campus	1. We can engage in activities that support or help other members despite the demands of our everyday lives (e.g., job, families) 2. We can leverage each other's professional connections (e.g., sharing of openings, tips, referrals), even though we do not usually meet one another in person 3. We can self-organize ourselves into subgroups with more refined interests, even though it will take effort to manage a variety of groups 4. Our community can take advantage of [a specific learning management system], even though many members are not experts in online technologies 5. When a problem arises, we can coordinate among ourselves to gain help from outside entities, even when the problem is complex or multi-faceted 6. Our community can sustain long term associations despite our virtual forms of interaction
ABC (n = 373) (*"World Campus students whom you have become acquainted with, regardless of whether they are now in a class with you"*)		

nity (or VCC) versus Acquaintance-Based Community (or ABC). Table 1 presents summary definitions for these concepts and anchors.

3.3.3 Research Findings

Community Constructs for Online Learners

We began by assessing the internal reliability for the overall scales for SOC and CCE; both were quite reliable, with Cronbach alphas of 0.93 and 0.96 respectively.

Table 2 SOC factors after removing cross-loading items

Common Identity; $M = 3.65$, $SD = 0.93$; $\alpha = 0.886$ (46.95% variance)
Fulfill my needs ($M = 3.48$, $SD = 1.12$, loading = 0.824)
Get what I need ($M = 3.67$, $SD = 1.08$, loading = 0.816)
Feel like a member of ($M = 3.81$, $SD = 1.11$, loading = 0.809)
Belong in the (M =3.89, $SD = 1.09$, loading = 0.784)
I can rely on others in ($M = 3.37$, $SD = 1.17$, loading = 0.734)
Friendship; $M = 2.01$, $SD = 1.09$; $r = 0.873$ (27.66% variance)
Have friends at ($M = 1.79$, $SD = 1.13$, loading = 0.925)
Feel close to others in ($M = 2.22$, $SD = 1.19$, loading = 0.878)

Because our goal was to investigate the latent structure that comprises feelings of online learning community, we next conducted exploratory factor analysis for the two scales.

Factors for Sense of Community

After employing a Varimax rotation to enhance interpretability of the factor analysis solution, we uncovered two factors from the analysis of the 10-item SOC scale. Following the guidance in (Ferguson & Cox, 1993), we next examined items that "cross-load", in other words, that load with a weight greater than 0.4 on two or more factors, or whose loading on two factors is very close. This led us to eliminate two items ("I feel that I matter to other students" and "I have a good bond with others in this community"). We also deleted "I feel connected to the World Campus community" because its loading on both factors was well beyond 0.4, suggesting it maps to both constructs. The final scale has seven items in two constructs (Table 2).

The *Common Identity* construct is represented by five items, and seems to stem from the SOC concepts of needs fulfillment and membership (Peterson et al., 2008), along with trust (Rovai et al., 2004). In contrast, *Friendship* appears to capture the emotional bonds one might expect in smaller groups such as projects, classes or social acquaintances. As seen in the table headers, although ratings of both constructs are relatively low, Common Identity has a higher mean value than Friendship (F(1,680) = 254.37, $p < 0.001$). It seems that when considering community in the large, online learners may experience these feelings primarily through their feelings of common identity with shared purposes, group membership and trust more than through interpersonal ties. However, this difference may also be an indication of how rare it is to have "friends" as part of an online learning program.

Factors for Community Collective Efficacy

An analogous exploratory factor analysis with the 24 CCE items, again using Varimax rotation, uncovered three latent constructs: Identity Regulation, Coordination

Table 3 CCE factors after removing cross-loaded factor

Identity Regulation; $M = 4.15$, $SD = 0.77$; $\alpha = 0.813$ (21.27% variance)
Follow social norms without supervision ($M = 4.46$, $SD = 0.84$, loading = 0.800)
Facilitate self-directed learning without full awareness of others ($M = 4.04$, $SD = 0.96$, loading = 0.700)
Encourage us to pursue a degree despite individual challenges ($M = 3.97$, $SD = 1.02$, loading = 0.652)
Leverage CMS despite technical complexities ($M = 4.14$, $SD = 0.97$, loading = 0.628)
Coordination; $M = 3.67$, $SD = 0.87$; $\alpha = 0.879$ (25.51% variance)
Sustain associations despite virtual interaction ($M = 3.54$, $SD = 1.16$, loading = 0.763)
Convey mission to outsiders without being forced ($M = 3.71$, $SD = 1.01$, loading = 0.731)
Coordinate to get help despite complexity of problem ($M = 3.80$, $SD = 1.02$, loading = 0.719)
Have individual influence despite speaking with a united voice ($M = 3.69$, $SD = 1.05$, loading = 0.692)
Self-organize into subgroups despite the management cost ($M = 3.62$, $SD = 1.08$, loading = 0.656)
Social Support; $M = 3.68$, $SD = 0.92$; $\alpha = 0.848$ (21.71% variance)
Help others despite everyday demands ($M = 3.62$, $SD = 1.13$, loading = 0.773)
Inform one another of news despite separation in time and space ($M = 3.90$, $SD = 1.09$, loading = 0.764)
Build interpersonal relationships despite turnover in courses ($M = 3.15$, $SD = 1.23$, loading = 0.734)
Welcome new members despite difference in joining times ($M = 4.04$, $SD = 1.00$, loading = 0.685)

and Social Support (a listing of the original scale and factor loadings is available online). Also as for SOC, we removed items with cross-loading, to render the eventual constructs more interpretable and non-overlapping (Ferguson & Cox, 1993). The final scale (Table 3) has 13 items distributed across three constructs.

Identity Regulation appears to represent foundational characteristics that ground a large group of online students to operate together as an online learning community. In particular, the items comprising this category are tied to the special circumstances of online education, such as earning an online degree in the midst of many individual challenges; using provided tools appropriately; and recognizing that online learning is largely self-directed. The strongest item in this construct refers to the social norms that must be in place for such a community to be successful, underscoring a belief of the sort "we know what we are doing and how to do it." This construct can be seen as a collective version of the common advice that online learners should be able to take the initiative and engage in self-directed learning (Moore & Kearsley, 2011), but here the emphasis is on the expectation that this is a collective responsibility of all students in a community.

A second construct is *Coordination*. The five items loading on this factor suggest a community that is able to engage in united action despite a variety of challenges, (e.g., computer-mediated communication, a lack of top-down organization, or the complexities of problems that may arise). In particular, online learners within the community manage and resolve conflicts (of interests or benefits) through coordination that allows individuals to express views and have influence. As a consequence, the community is able to act unitedly as one entity. It is also noteworthy that while sustaining associations loads most strongly on this factor, it has a rating barely above the midpoint of a 5-point rating scale ($M = 3.54$, $SD = 1.16$); this may indicate some difficulty in sustaining associations for online students.

Finally, *Social Support* is quite intuitive as a community capacity. The items that comprise this construct relate to the interpersonal help, support, and maintenance of ties. It may be that some interpersonal "jobs" are easier than others (e.g., compare welcoming new members with building interpersonal relationships), but this sort of capacity for helping one another seems also to be an element of collective efficacy.

Comparing means among the three constructs, a repeated measures ANOVA (with Greenhouse-Geisser correction for sphericity) revealed a significant difference among the constructs ($F(1.94, 1314.95) = 194.57$, $p < 0.001$). Post hoc tests with Bonferroni correction showed that Identity Regulation was significantly higher than both Coordination and Social Support, which did not differ. This mean difference complements the earlier finding of a higher mean for Common Identity versus Friendship in the SOC constructs, and helps to reinforce the importance of shared identity experiences and associated community responsibilities for this online campus of distance learners.

Contrasting Different Definitions of Community

We compared the means of the community constructs for the VCC and ABC groups ($n = 367$ and 373 respectively; see Table 4). A 2 (ABC vs. VCC, between) × 2 (Common identity vs .Friendship for SOC, within) ANOVA revealed no interaction effect between SOC types and community definition ($F(1,738) = 0.03$, $p = 0.87$). This is not surprising given that the means are virtually identical for both constructs. However, we found the main effect of SOC constructs ($F(1,738) = 984.69, p < 0.001$) for Common Identity to have a higher mean than Friendship (i.e., replicating what we found when we analyzed the entire dataset). There was no main effect of the community definitions $F(1,738) = 0.08$, $p = 0.78$. Put it in other words, instructing respondents to focus on World Campus in the large, or on acquaintances within World Campus, has no effect on feelings of either Common Identity or Friendship. We were surprised to find this, as we had expected to see higher ratings on items relating to interpersonal ties when respondents were instructed to focus on acquaintances. It may simply be that students' ego networks in World Campus are too small or loosely connected to play much of a role in feelings of community.

We also analyzed the three CCE constructs (Identity Regulation vs. Coordination vs. Social Support) as a within-subjects factor across the two community definition groups. In this case, the ANOVA revealed a significant two-way interaction between the three constructs and the two definition conditions ($F(2,676) = 4.60$, $p < 0.05$).

Table 4 Community construct means for ABC and VCC

	Ident.	Friend.	Reg.	Coord.	Social
VCC	3.72	2.00	4.23	3.70	3.67
ABC	3.74	2.03	4.06	3.66	3.67

Further, we examined simple main effects separately for the two definition conditions, and found that for each subgroup there were statistically significant differences among the three constructs (F(2,676) = 73.05, $p < 0.001$ for ABC and F(2,676) = 130.44, $p < 0.001$ for VCC). A post hoc test with Bonferroni adjustment for multiple pair comparisons indicates that only the contrast of Identity Regulation is significant ($p < 0.001$). In other words, for both ABC and VCC, Identity Regulation has a higher mean value than Coordination and Social Support. At the same time, the simple effects of community definition were significant only for Identity Regulation (F(1,677) = 9.14, $p < 0.01$); respondents gave the more abstract VCC definition reported high collective efficacy on this construct than those given the acquaintance-based definition. Again, this is easily seen in a visual comparison of the means, where Identity Regulation differs by 0.17 while the other constructs' means are virtually identical.

In sum, only the CCE construct of Identity Regulation appeared to be sensitive to the two ways in which we define community. The differences were as one would expect, with the VCC definition evoking higher ratings of what is expected by members of World Campus. Recall that our sample sizes for the between-subjects variable were 367 for VCC and 373 for ABC; the comparison has a power value of 0.88, indicating sufficient sample sizes (Faul, Erdfelder, Buchner, & Lang, 2009).

In reviewing the observed pattern of means, it seems intuitive that Identity Regulation receives higher collective efficacy ratings when viewing the community as the entire World Campus. However, it is surprising that neither the SOC construct of Friendship nor the CCE construct of Social Support, receive higher ratings when the community is understood to be acquaintance-based. It may be that one's ego network is a mix of individuals, only some of whom can contribute to feelings of friendship or social support.

4 Limitation

Despite the triangulation of different sources (i.e., stakeholders' voices) and methods, our empirical studies reported above were conducted in only one high-quality, paid online degree program of a well-recognized university located in America. Therefore, how our findings can be applied to other online degree programs that are less competitive and more affordable needs future work. More generally, we note the wide variety of possible online learning settings, ranging from online video watching, to MOOCs, to more formalized educational programs, and thus call for more comparison work to validate and extend the reported findings in this particular context, and consider other mediators including cost, motivations, level of commitment and expectations, and student characteristics. Meanwhile, although our survey responses were collected from students of different majors and backgrounds over the campus, the two interview studies were mostly based on conversations with students or instructors associated with an i-school, which may only represent the online teaching and learning practices of tech-savvy users. Therefore, we note that future work will be needed to validate and generalize the interesting patterns revealed in our interviews.

5 Discussion

Our empirical studies suggest that both instructors and students are aware of the importance of establishing identity transparency in online classes (e.g., instructors' practices in publicizing others' work and encouraging self-introductions, and students' strategies in sharing and gleaning one another's shared personal identity by reading others' posts). This type of increased mutual knowledge may also lead to continued collaboration, which is reported in both groups' accounts. More generally, both two interview studies emphasized the critical role of shared identities in how they felt connections and fostered relationships among peer learners. Based on the two key stakeholders' perspectives, we found that learners were quite capable of making social inference and encouraged to form small groups based on active constructions of their own and other peers' shared identities. This results aligned with information exchange theory (Stuart, Dabbish, Kiesler, Kinnaird, & Kang, 2012), which claims that information sources are more like to initiate new information exchanges with receivers who are perceived to be similar; also, receivers are more likely to accept information from sources who are similar than from sources who are dissimilar. In the same vein, our findings contribute to this body of work, documenting how distance learners seek out—or simply discover along the way—elements of shared identity that contribute to feelings of connection with one another. Construal level theory suggests that prior to interpersonal interaction, gleaning any information that reveals similarities with an unknown individual can engender a more vivid and accurate perception of a remote person (Marlow & Dabbish, 2012). This suggests a clear direction for CSCL designers interested in promoting feelings of community: design ways to collect and convey information that promotes shared identity among the learners. Future work is needed to examine how identity transparency with forum posts or more modularized profile among online learners might nurture more remote peer relationships in a systematic way.

With respect to techniques for facilitating social interaction in online classes, we found that both instructors and students favor the immediacy and realness of live sessions, or the relatively instant availability that arises out of smaller social structures (e.g., project group). The preference of peers' or instructors' instant availability is surprising given that a large percentage of online learners are distributed across different time zones and that concurrency may not be a necessity in the context of distance learning at all. However, the readiness for immediate communication also points to the need for more empirical research on the effect of temporal proximity and (semi)-synchronous interaction on the trust and group-efficacy among distributed learners. In addition, prior work has indicated that online students are often confronted with social issues derived from other facets in their immediate life (e.g., a sick baby), and suffer from insufficient time for learning (Benda, Bruckman, & Guzdial, 2012). In this regard, our work extends that distance learners might feel these constraints more severely, but still merit the value from immediate interaction with their remote peers or instructors.

Contrasting two stakeholders' perspectives, instructors emphasized the orchestration of public activities where students can feel engaged and thus participate in the class level; students strategically consider opportunistic gains in the settings of small-group learnings, taking account of temporal proximity, immediate communication, and appropriate expectations when arranging collaborative learning activities. A paralleled conversations with the two activity stakeholders revealed that instructors are more driven by the collective reaction and class-level participation, whereas students are often involved in the practice of vetting competent group member candidates. Therefore, we call for more research efforts in measuring and bridging the gap between pedagogical practices and students' interests in forming peer connections and having collaborative learning activities from afar.

More broadly in our larger scale quantitative survey study, identity regulation was the strongest factor underpinning feelings of community collective efficacy. Friendship (feelings of closer relationship) was less likely to play a role. These findings suggest that feelings of friendship may be hard to find in an online learning community, despite any collaborative learning activities that may take place, and repeated encounters with peers who share a general learning trajectory (e.g., cohorts of a major). To speculate on this phenomenon, we proposed two possibilities: it is one thing that the intimate social bonds are formed due lack of expectation and thus underuse of existing channels, it is another that friendship is not what characterizes such kind of community. Part of our interview findings may help account for the tenuous friendship in the survey study: it is hard to feel connected without short turnaround communication cycles, but such friendship is "almost" there when students have gone through a supportive group project together and encounter one another repeatedly. More research work is needed to uncover the issues behind weak ties among online learners.

6 Conclusion

According to our synthesized findings and discussions, we raise five design implications arising from our study of social elements in online learning environments. (1) Tools for online learners might try to leverage the "upfront" orienting construct of shared identity, using knowledge of shared community commitment as a basis for interpersonal connections. (2) Our interviews demonstrated both social and cognitive value of small-group interaction and "almost friendship," whereas our survey study indicated that learners' significantly lower efficacy in managing friendships as part of community. Designers for online learning platform might consider the benefits of adding more support for friendship building, for instance addressing the relative lack of social cues that foster interpersonal affinity (Liebman & Gergle, 2016). For instance, private messages (e.g., whispering functions (Haythornthwaite, 2000)) and backchannels (Du et al., 2012) appear to facilitate a sense of community, but such messaging services are rarely available outside a group of classmates. (3) Collaborating within the same temporal rhythm may help to compensate for the fact that they are not "together" in the real world. Specifically, having a matched classwork rhythm in such contexts, we found the important role of real-time or close-to-real-time interaction (e.g., live session, SNSs app use) in creating such bonds. This suggests the importance of offering real-time communication tools to connect small social structures among online learners, as noted in the study of video meetings (Cao et al., 2010) and video-based discussion activity in MOOCs (Kulkarni, Cambre, Kotturi, Bernstein, & Klemmer, 2015). Such interpersonal connectivity is important for online students to initiate direct interaction (Lampe, Wash, Velasquez, & Ozkaya, 2010), and to tolerate the occasional overdue contribution (Strijbos & De Laat, 2010). Therefore, our mixed findings call for design and research efforts to examine how technologies can afford such temporal proximity cues and address such needs. (4) Group and class-based social connections stem from direct peer interaction and repeated encounters, whereas university-based connections among peer learners appear to arise from self-identification with the organization. Identity-enabled modules, such as profiles or other forms of symbolized university identity should be considered in the process of engaging online learners with regards to their organizational attachment.

Acknowledgements We thank the many students of World Campus who responded to the survey, and instructors who either participated in our interview study, or helped recruit participants in their classes. This research was partially supported by a Research Initiation Grant from Penn State's Center for Online Innovation and Learning, and by the College of Information Sciences and Technology.

References

Appiah-Kubi, K., & Rowland, D., PEER support in MOOCs: The role of social presence. In *Proceedings of the Third (2016) ACM Conference on Learning@ Scale* (pp. 237–240). ACM. https://doi.org/10.1145/2876034.2893423.

Ashar, H., & Skenes, R. (1993). Can Tinto's student departure model be applied to nontraditional students? *Adult Education Quarterly, 43*(2), 90–100.

Benda, K., Bruckman, A., & Guzdial, M. (2012). When Life and Learning Do Not Fit. *ACM Transactions on Computing Education, 12*(4), 1–38. https://doi.org/10.1145/2382564.2382567.

Borge, M., & Goggins, S. (2014). Towards the facilitation of an online community of learners: Assessing the quality of interactions in Yammer. In *Proceedings of ICLS* (Vol. 14, pp. 753–761).

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101.

Brown, D. J., McHugh, D., Standen, P., Evett, L., Shopland, N., & Battersby, S. (2011). Designing location-based learning experiences for people with intellectual disabilities and additional sensory impairments. *Computers & Education, 56*(1), 11–20. https://doi.org/10.1016/j.compedu.2010.04.014.

Brown, R. E. (2001). The process of community-building in distance learning classes. *Journal of Asynchronous Learning Network, 5*(2), 18–35.

Cao, X., Sellen, A., Brush, A. J. B., Kirk, D., Edge, D., & Ding, X. (2010). Understanding family communication across time zones, in *Proceedings of the 2010 ACM Conference on Computer Supported Cooperative Work—CSCW'10*, p. 155. https://doi.org/10.1145/1718918.1718947.

Carr, S. (2000). As distance education comes of age, the challenge is keeping the students. *Chronicle of Higher Education*, A39–A41.

Clegg, T., Yip, J. C., Ahn, J., Bonsignore, E., Gubbels, M., Lewittes, B., et al. (2013). *When face-to-face fails: Opportunities for social media to foster collaborative learning*. Citeseer: In Tenth international conference on computer supported collaborative learning.

Coetzee, D., Fox, A., Hearst, M. A., & Hartmann, B. (2014). Chatrooms in MOOCs : All Talk and No Action. In *Proceedings of the First ACM Conference on Learning @ Scale Conference—L@S'14*, 127–136. https://doi.org/10.1145/2556325.2566242.

Du, H., Rosson, M. B., & Carroll, J. M. (2012). Augmenting classroom participation through public digital backchannels. In *Proceedings of the 17th ACM International Conference on Supporting Group Work (GROUP'12)*, pp. 155–164. https://doi.org/10.1145/2389176.2389201.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*(4), 1149–1160.

Ferguson, E., & Cox, T. (1993). *Exploratory Factor Analysis : A Users' Guide, 1*(2), 84–94.

Ferschke, O., Howley, I., Tomar, G., Yang, D., Liu, Y., & Rosé, C. P. (2015). Fostering discussion across communication media in massive open online courses. In *Proceedings of the 11th International Conference on Computer Supported Collaborative Learning*, in review.

Gašević, D., Zouaq, A., & Janzen, R. (2013). Choose your classmates, your GPA is at stake! *American Behavioral Scientist, 57*(10), 1460–1479. https://doi.org/10.1177/0002764213479362.

Goggins, S. P., Laffey, J., & Gallagher, M. (2011). Completely online group formation and development: small groups as socio-technical systems. *Information Technology & People, 24*(2), 104–133. https://doi.org/10.1108/09593841111137322.

Guo, Z., Tan, F. B., & Cheung, K. (2010). Students' uses and gratifications for using computer-mediated communication media in learning contexts students' uses and gratifications for using computer -mediated communication media in learning contexts students' uses and gratifications for using C. *Communications of the Association for Information Systems, 27*(20), 339–378.

Hallberg, L. R. M. (2006). The "core category" of grounded theory: Making constant comparisons. *International Journal of Qualitative Studies on Health and Well-Being, 1*(3), 141–148. https://doi.org/10.1080/17482620600858399.

Haythornthwaite, C. (2000). Online personal networks: Size, composition and media use among distance learners. *New Media and Society*. https://doi.org/10.1177/14614440022225779.

Haythornthwaite, C., Kazmer, M. M., Robins, J., & Shoemaker, S. (2000). Community development among distance learners: Temporal and technological dimensions. *Journal of Computer-Mediated Communication*, *6*(1), 0.

Kena, G., Musu-Gillette, L., Robinson, J., Wang, X., Rathbun, A., Zhang, J., … Velez, E. D. V. (2015). The condition of education 2015. NCES 2015-144. *National Center for Education Statistics*.

Kizilcec, R. F., & Halawa, S. (2015). Attrition and achievement gaps in online learning. In *Proceedings of the Second (2015) ACM Conference on Learning @ Scale - L@S '15,* (pp 57–66). https://doi.org/10.1145/2724660.2724680.

Koh, M. H., Barbour, M., & Hill, J. R. (2010). Strategies for instructors on how to improve online groupwork. *Journal of Educational Computing Research, 43*(2), 183–205. https://doi.org/10.2190/EC.43.2.c.

Kulkarni, C. Nmay, Cambre, J., Kotturi, Y., Bernstein, M. S., & Klemmer, S. R. (2015). Talkabout: making distance matter with small groups in massive classes. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing—CSCW'15*, pp. 1116–1128. https://doi.org/10.1145/2675133.2675166.

Lampe, C., Wash, R., Velasquez, A., & Ozkaya, E. (2010). Motivations to participate in online communities. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pp. 1927–1936. https://doi.org/10.1145/1753326.1753616.

Liebman, N., & Gergle, D. (2016). It's (Not) simply a matter of time: The relationship between CMC cues and interpersonal affinity. *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing*, pp. 570–581. https://doi.org/10.1145/2818048.2819945.

Marlow, J., & Dabbish, L. (2012). Designing interventions to reduce psychological distance in globally distributed teams. *Cscw'12*, 163–166. https://doi.org/10.1145/2141512.2141568.

Mcelrath, E., & Mcdowell, K. (2008). Pedagogical strategies for building community in graduate level distance education courses. *Journal of Online Learning and Teaching, 4*(1), 117–127.

Merriam, S. B. (2002). *Qualitative research in practice: Examples for discussion and analysis*. Jossey-Bass Inc Publications.

Moore, M. G., & Kearsley, G. (2011). *Distance education: A systems view of online learning*. Cengage Learning.

Mustafaraj, E., & Bu, J. (2015). The visible and invisible in a MOOC discussion forum. In *Proceedings of the Second (2015) ACM Conference on Learning @ Scale—L@S'15*, 351–354. https://doi.org/10.1145/2724660.2728691.

Peterson, N. A., Speer, P. W., & McMillan, D. W. (2008). Validation of a brief sense of community scale: Confirmation of the principal theory of sense of community. *Journal of Community Psychology, 36*(1), 61–73. https://doi.org/10.1002/jcop.

Rovai, A. P., Wighting, M. J., & Lucking, R. (2004). The classroom and school community inventory: Development, refinement, and validation of a self-report measure for educational research. *Internet and Higher Education, 7*(4), 263–280. https://doi.org/10.1016/j.iheduc.2004.09.001.

Shachar, M., & Neumann, Y. (2003). Differences between traditional and distance education academic performances : A meta-analytic approach. *International Review of Research in Open and Distance Learning*, *4*(2).

Shelley, M. (2008). Considering students' perceptions: The distance education student satisfaction model Ismail Sahin. *Educational Technology & Society, 11,* 216–223. https://doi.org/10.2307/jeductechsoci.11.3.216.

Soller, A., Wiebe, J., & Lesgold, A. (2002). A machine learning approach to assessing knowledge sharing during collaborative learning activities. In *Proceedings of the Conference on Computer Support for Collaborative Learning Foundations for a CSCL Community—CSCL'02*, (1), 128. https://doi.org/10.3115/1658616.1658635.

Stahl, G. (2011). Theories of cognition in CSCW. In *Proceedings of the 12th European Conference on Computer Supported Cooperative Work (ECSCW 2011)* (pp. 193–212). https://doi.org/10.1007/978-0-85729-913-0_11.

Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory.* Sage Publications, Inc.

Strijbos, J. W., & De Laat, M. F. (2010). Developing the role concept for computer-supported collaborative learning: An explorative synthesis. *Computers in Human Behavior, 26*(4), 495–505. https://doi.org/10.1016/j.chb.2009.08.014.

Stuart, H. C., Dabbish, L., Kiesler, S., Kinnaird, P., & Kang, R. (2012). Social transparency in networked information exchange. *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work - CSCW'12*, 451. https://doi.org/10.1145/2145204.2145275.

Sun, N., & Rosson, M. B. (2017). *Finding the community in online education: It's in the instructors' eyes*. Philadelphia, PA: International Society of the Learning Sciences.

Sun, N., Rosson, M. B., & Carroll, J. M. (2018). Where is community among online learners?: Identity, efficacy and personal ties. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (p. 292). ACM.

Sun, N., Wang, X., & Rosson, M.B. (2019). How do distance learners connect? In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)* (p.12). ACM, New York, NY, USA, Paper 432. https://doi.org/10.1145/3290605.3300662.

Tinto, V. (1975). Dropout from higher education: A theoretical synthesis of recent research. *Review of Educational Research Winter, 45*(1), 89–125. https://doi.org/10.3102/00346543045001089.

Vygotsky, L. S. (1980). *Mind in society: The development of higher psychological processes*. Harvard university press.

Walther, J. B. (2002). Time effects in computer-mediated groups: Past, present, and future. *Distributed Work*, 235–257.

Williams, B. A. (2015). Peers in MOOCs: Lessons based on the education production function, collective action, and an experiment. In *2nd ACM Conference on Learning at Scale, L@S 2015*, 287–292. https://doi.org/10.1145/2724660.2728677.

Xing, W., Kim, S., & Goggins, S. (2015). Modeling performance in asynchronous CSCL: An exploration of social ability, collective efficacy and social interaction. *Exploring the Material Conditions of Learning: Proceedings of the Computer Supported Collaborative Learning (CSCL 2015), International Society of the Learning Sciences*, 276–283. Retrieved from https://www.isls.org/cscl2015/papers/MC-0268-FullPaper-Goggins.pdf.

Chapter 8
Embodied Learning in a Digital World: A Systematic Review of Empirical Research in K-12 Education

Yiannis Georgiou and Andri Ioannou

1 Introduction

Embodied learning appears to have gained ground during the last decade, seeking for the ways in which embodied cognition theory may be enacted and applied in the field of education. Embodied learning, as an application area of embodied cognition theory, constitutes a contemporary pedagogy of learning, which emphasizes the use of the body in the educational practice (Antle et al., 2009; Antle, 2013; Barsalou, 2010; Kosmas, Ioannou, & Retalis, 2018). As Nguyen and Larson (2015) explained: "Learners are simultaneously sensorimotor bodies, reflective minds, and social beings. Embodied learning provides a way through which alternative forms of teaching and learning can be integrated and accepted into the classroom" (p. 342).

It is not surprising that during the last decade there was a rapid development of educational technologies, which enable embodied learning practices in education. The widespread population of affordable motion-based technologies and natural user interfaces (e.g., Wii, Xbox Kinect, Leap Motion), in combination with the emergence of immersive interfaces based on mixed or virtual reality, have opened the doors for the design of technology-enhanced embodied learning environments (Enyedy, Danish, & DeLiema, 2015). In its essence, technology-enhanced embodied learning environments compose an emergent category of digital environments, which integrate gestures or even full-body movement into the act of learning (Johnson-Glenberg, Savio-Ramos, & Henry, 2014; Ibánez & Wang, 2015).

Y. Georgiou (✉) · A. Ioannou
Cyprus Interaction Lab, Department of Multimedia and Graphic Arts, Cyprus University of Technology, Cyprus University of Cyprus, 30 Archbishop Street, 3036 Limassol, Cyprus
e-mail: ioannis.georgiou@cut.ac.cy

A. Ioannou
e-mail: andri.i.ioannou@cut.ac.cy

Cyprus University of Cyprus, Julia House, 3 Themistokli Dervi Street, Nicosia 1066, Cyprus

P. Díaz et al. (eds.), *Learning in a Digital World*, Smart Computing and Intelligence, https://doi.org/10.1007/978-981-13-8265-9_8

As argued by Maliverni and Pares (2014), technology-enhanced embodied learning environments create new possibilities due to their affordances to promote psychomotor learning experiences, while also involving users cognitively. At the same time, due to their novelty and wide-ranging areas of applicability, technology-enhanced embodied learning environments are highly intriguing to researchers, instructional designers, technology specialists, and educators; however, their integration in mainstream education is at very slow pace (Abrahamson & Sánchez-García, 2016). At the same time, the evidence of the potential effectiveness of technology-enhanced embodied learning environments is still sparse and fragmented (Maliverni & Pares, 2014), while many psychologists and learning scientists are concerned that such activities are nothing more than "bells and whistles," which may falsely be perceived as educational (Goldinger, Papesh, Barnhart, Hansen, & Hout, 2016). It thus appears to be an urgent need to synthesize existing empirical research on the topic, for drawing some evidence-based conclusions about the effectiveness of technology-enhanced embodied learning environments.

Malinverni and Pares (2014) reviewed 31 studies focusing on full-body interaction learning environments, as a subcategory of technology-enhanced embodied environments, published from 2003 to 2013. However, as they have reported, their review did not result in some conclusive findings about the educational value of technology-enhanced embodied learning environments. This may be attributed to the fact that their review was mostly based on conference papers (26 out of the 31 studies), typically providing shorter debriefs of the conducted research. At the same time, technology-enhanced embodied learning environments allowing interactions via gestures and hand movements were out of scope in the review of Malinverni and Pares (2014). In another study, Sheu and Chen (2014) reviewed 59 studies for investigating the trends of gesture-based environments in education—a subcategory of technology-enhanced embodied environments—published from 2001 to 2013. However, Sheu and Chen (2014) investigated how the gesture-based embodied environments were applied pedagogically aiming at identifying pedagogical differences between the learning domains; the authors did not investigate the impact of the embodied environments on students' learning. In addition, as their review focused particularly on gesture-based technologies, full-body learning environments were out of scope.

The present review study examines the empirical research, which has been published during the last decade, between the years 2008 and 2017 and is concerned with students' learning outcomes across the cognitive, affective, and psychomotor domains linked to their experience in a technology-enhanced embodied learning environment. As such, our effort addresses the need for collecting and synthesizing empirical evidence regarding the value of this emerging type of educational environments; this need has not yet been addressed sufficiently by prior review efforts. In addition, rather than focusing on a subset of technology-enhanced embodied learning environments (e.g., gesture-based or full-body), the present review sets as a unifying axis the notion of embodied cognition for capturing all of the empirical studies related to the topic. More specifically, the present study examines empirical studies on technology-enhanced embodied learning environments in K-12 education. Five research questions were addressed:

(1) What types of technology-enhanced embodied learning environments *(type of embodied technologies, duration of embodied learning interventions)* are utilized in K-12 education?
(2) What are the educational contexts *(learning disciplines and domains*) in which technology-enhanced embodied learning environments are used?
(3) What research methods *(research designs and assessment techniques)* are used for evaluating students' outcomes during the implementations of technology-enhanced embodied learning environments?
(4) What kinds of learning outcomes across the cognitive, affective, and psychomotor domains are evident as students participate in technology-enhanced embodied learning environments?
(5) Do students learn more through their participation in technology-enhanced embodied learning environments, as compared to other forms of instruction and interfaces?

The rest of the manuscript continues by presenting a definition of embodied learning, focusing on technology-enhanced embodied learning environments. We then present the methodology of the review as well as a synopsis and synthesis of our findings, followed by a set of guidelines for future research and practice in the field.

2 Embodied Learning Defined

Prior research on educational systems has highlighted the need for incorporating aspects of embodiment, motion, and physicality in technology-enhanced learning environments (Abrahamson & Raúl Sánchez-García, 2016; Birchfield et al., 2008; Melcer & Isbister, 2016). This direction stems from the concept that cognition is influenced and shaped by the bodily activity; as such, rather than being separate, perception, cognition, and action are considered as closely intertwined (Antle, 2013; Barsalou, 2010). Meanwhile, the widespread population of affordable motion technologies has opened the doors for the design of technology-enhanced learning environments, based on the principles of embodied cognition (Ibánez & Wang, 2015). Yet, little is known about the pedagogical affordances of technology-enhanced environments for embodied learning (Johnson-Glenberg & Megowan-Romanowicz, 2017). This does not imply that there has been no research on the effectiveness and pedagogical affordances of technology-enhanced environments for embodied learning in K-12 education, but rather that research evidence is thinly spread. As such, according to Maliverni and Pares (2014), this situation provides a "fragmented panorama" from which meaningful conclusions may not be deduced. Also, Johnson-Glenberg et al. (2014a, b) have suggested that, despite the increase of embodied digital environments, a more rigorous understanding of embodied learning through technology-enhanced learning environments is needed.

Table 1 The taxonomy of technology-enhanced embodied learning environments, as presented in Johnson-Glenberg, Megowan-Romanowicz, Birchfield, and Savio-Ramos (2016)

	Level 1	Level 2			Level 3			Level 4
Sensorimotor engagement	L	L	L	H	H	H	L	H
Gestural congruency	L	L	H	L	H	L	H	H
Immersion	L	H	L	L	L	H	H	H

H High, *L* Low

Johnson-Glenberg et al. (2014a, b, 2016) have proposed a taxonomy of four levels of embodiment achieved with current educational technologies. The degrees of embodiment are defined by the following three aspects: (a) the amount of sensorimotor engagement, as achieved through bodily motion; (b) the amount of gestural congruency, which is achieved through the relevance of the gesture with the content to be learned; and (c) the amount of immersion, which is influenced to a great degree by the type and configuration of the content's display. Table 1 provides an overview of eight sets which are binned along the three aspects (sensorimotor engagement, gestural congruency, immersion), thus resulting in four progressive levels of embodiment.

According to the two lowest levels of the taxonomy, embodiment is very limited to non-existed, given that the gestural congruency is not a defining construct in the lesson, neither there is a contribution of movement to the reification of the educational content. These lowest levels of the taxonomy include desktop-based simulations or videos that are often passively viewed in smaller displays (e.g., desktops or handheld devices), thus providing no opportunities for sensorimotor engagement and immersion.

In contrast, in the two upper levels of the taxonomy, embodiment is observed in higher degrees as the gestural congruency is a defining aspect of the educational experience. For example, the embodied learning environments might be equipped with motion tracking systems (e.g., Wii, Xbox Kinect, or Leap Motion) to enable hand gestures or body movements that are closely mapped to the educational content to be learned. These learning environments typically include large screen displays, floor projections, 360° head-mounted displays (HMD), and virtual reality or mixed reality rooms, which are also perceived as highly immersive. A more recent taxonomy provided by Skulmowski and Rey (2018) further supports that such learning environments enable high bodily engagement and embodiment integration in the learning task, given that they allow a high coupling between movement and the educational content to be learned.

The present review is concerned with the highest levels of the taxonomy (i.e., Levels 3 and 4); lower levels of embodiment are not in the scope of this work. As part of our analysis, we focused on the type of technology-enhanced embodied learning environments utilized, the research methods adopted for their evaluation, and the educational contexts in which they are implemented. At the core of this review study, we investigated students' learning outcomes across the cognitive, affective, and psychomotor domains, while we examined the effectiveness of technology-enhanced embodied learning environments, as compared to other interfaces and forms of instruction.

3 Method

3.1 Data Collection

The studies analyzed in this literature review covered empirical research published from 2008 to 2017. The published literature was surveyed using four electronic databases: Education Research Complete [via EBSCO], ERIC, JSTOR, and Scopus, which are considered among the most enriched and popular academic databases.

The retrieving keywords were classified into two groups (Group 1: Approach type, Group 2: Interaction type), in order to retrieve as many relevant articles as possible (Table 2). For surveying the published research in the selected databases, we searched the abstracts of the indexed studies by combining each keyword with the following terms: "Students", "Learners", "Learning gains", "Learning outcomes", "Classroom", and "School"; this ensured that the retrieved results would be mostly restricted in K-12 educational settings.

After performing all possible combinations, we retrieved 306 unique studies within the field of interest, namely, technology-enhanced environments for embodied learning in K-12 education. This corpus of studies was subsequently filtered according to five selection criteria. In particular, to be included in the corpus of the reviewed studies, a study ought to have met all five criteria: (1) Source type: The study should have been published in English as a full paper in an academic journal; (2) Research methods: The study should be empirical, providing primary data derived from quantitative, qualitative, or mixed designs; (3) Type of intervention: The study should report on the investigation of a technology-enhanced embodied learning environment in the upper levels (third and fourth levels) of the embodied taxonomy, as suggested by Johnson-Glenberg et al. (2014a, b); (4) Research focus: The study should be related to the research focus of the present review, i.e., reporting on students' learning outcomes across the cognitive, affective,

Table 2 Retrieval keywords per group

Group name	Search term/phrases
Approach type	"Embodied cognition"; "Embodied learning"; "Embodied pedagogy"; "Embodied education"; "Embodied play"
Interaction type	"Embodied interaction"; "Full-body interaction"; "Whole-body interaction"; "Bodily interaction"; "Gesture-based interaction"; "Touchless interaction"; "Motion-based interaction"

and psychomotor domains; and (5) Participants: The study participants should be K-12 students.

After applying these selection criteria, 24 eligible peer-reviewed, journal articles remained in the review corpus. In addition, a complementary search in Google Scholar, and using the same selection criteria, led to the retrieval of 10 more empirical studies. This initial corpus was enriched using the "ancestry" method (Cooper, 1982), according to which we searched the references of the identified research articles for empirical studies that could be included in the present review. This process yielded seven additional articles.

Overall, a total of 41 studies met all the inclusion criteria and were selected for this review; these articles are marked with an asterisk in the reference section.

3.2 Coding and Analysis

To answer the first three research questions, focused on (a) the types of technology-enhanced embodied learning environments (RQ1), (b) the educational contexts in which these were implemented (RQ2), and (c) the research methods adopted for evaluating the implementations (RQ3), we conducted a content analysis of the reviewed studies, without having any predetermined categories in mind.

To answer RQ4, we coded the students' learning outcomes across the cognitive, affective, and psychomotor domains as in Table 3. Researchers have traditionally focused on the cognitive dimension of learning outcomes (e.g., Bloom, 1956; Gagné, 1977); yet, this taxonomy has been later extended to include effective outcomes (e.g., Baker & Mayer, 1999, Krathwohl et al., 2002; Wouters, van der Spek, & van Oostendorp, 2009) and psychomotor outcomes (e.g., Kraiger, Ford, & Salas, 1993; Wouters et al., 2009).

Finally, to answer RQ5, we focused on the empirical studies examining the learning effectiveness of technology-enhanced embodied learning environments compared to other forms of instruction and interfaces. These studies were categorized according to the reported learning effectiveness: (a) Positive effect (positive learning outcomes in the embodied learning condition are better compared to the control/comparison condition), (b) Negative effect (learning outcomes in the comparison/control group are better compared to the embodied learning condition), and (c) No difference (similar outcomes in both conditions).

To enhance the reliability of the coding process, an inter-rater reliability was performed between two coders. An initial sample of six articles (15% of the reviewed corpus) was coded independently by the two authors with very high agreement (Cohen's k ranged between 0.82 and 0.95 for the coding categories). All disagreements were discussed and resolved, and then the first author continued with the coding of the rest of the 35 articles (85% of the reviewed corpus).

Table 3 Classification of the learning outcomes

Domain	Definition	Learning outcomes
Cognitive	Relates to the intellectual aspects of learning	• Information searching skills • Knowledge acquisition and conceptual understanding • Cognitive skills (e.g., visual and auditory memory, attention, focus) • Problem-solving skills (e.g., analyzing, synthesizing, summarizing, inferring) • Metacognition skills (e.g., self-regulation, self-assessment)
Affective	Relates to the emotional aspects of learning	• Motivational outcomes (e.g., interest and curiosity, willingness to learn) • Engagement (e.g., immersion, sense of presence/flow, active participation) • Social behaviors (e.g., social interactions, collaboration) • Attitudes and dispositions
Psychomotor	Relates to the physical aspects of learning	• Physical skills (e.g., movement, strength, balance, speed, control, coordination, agility)

4 Findings

4.1 Overview of the Reviewed Empirical Studies

A total of 41 empirical studies were identified, published from 2008 to 2017, reporting on the impact of embodied learning environments for K-12 students. A total of five studies were published between 2008 and 2010 (12.2%); another eight studies were published during 2011–2013 (19.5%), while 28 studies were published during 2014–2017 (68.3%). A considerable peak in the published studies can be observed during the period of 2014–2017, indicating the increasing interest on the topic.

Table 4 presents the distribution of the reviewed papers per journal. Most of the reviewed studies (48.8%) were published in educational–technology-related journals, while the most prominent journals were "*Computers & Education*" (14.6%) and "*Computer-Supported Collaborative Learning*" (7.3%).

What follows is the presentation of the main findings per the research question.

Table 4 Distribution of reviewed studies per journal

Journal domain	Journal title	N (%)
Educational Technology	• Computers & Education • Computer-Supported Collaborative Learning • Journal of Science Education & Technology • Technology, Knowledge & Learning • Educational Technology, Research & Development • Educational Technology & Society • TOJET: The Turkish Online Journal of Educational Technology • Educational Media International • Journal of Interactive Learning Research • Journal of Computer-Assisted Learning • International Journal of Computer-Supported Collaborative Learning • International of Artificial Intelligence in Education	6 studies (14.6%) 3 studies (7.3%) 2 studies (4.9%) 1 study (2.4%) 1 study (2.4%) 1 study (2.4%) 1 study (2.4%) 1 study (2.4%) 1 study (2.4%) 1 study (2.4%) 1 study (2.4%) 1 study (2.4%) **Total: 20 studies (48.8%)**
Education & Psychology	• ZDM Mathematics Education • Problems of education in the twenty-first century • Journal of Educational Psychology • Journal of Learning Analytics • Journal of Mathematical Behavior	2 studies (4.9%) 2 studies (4.9%) 1 study (2.4%) 1 study (2.4%) 1 study (2.4%) **Total: 7 studies (17.1%)**
HCI	• International Journal of Child-Computer Interaction • Interacting with Computers • Advances in Human-Computer Interaction • Computers in Human Behavior	3 studies (46.4%) 1 study (2.4%) 1 study (2.4%) 1 study (2.4%) **Total: 6 studies (14.6%)**
Games & Simulations	• International Journal of Gaming and Computer-Mediated Simulation • Games for Health Journal • International Journal of Game-based learning	2 studies (4.9%) 2 studies (4.9%) 1 study (2.4%) **Total: 5 studies (12.2%)**
Computer science applications	• Journal of King Saud University-Computer and Information Sciences • Advances in Multimedia • Interaction Design and Architecture(s) Journal	1 study (2.4%) 1 study (2.4%) 1 study (2.4%) **Total: 3 studies (7.3%)**

4.2 *Type of Embodied Learning Environments (RQ1)*

According to our analysis, most of the reviewed studies included embodied learning environments grounded on *gesture-based technologies*, which according to Johnson, Adams, and Cummins (2012) allow the user to interact directly via the employment of gestures as naturally as in daily life (e.g., hand gestures, finger flips or even facial expressions, and eye movements), rather than *full-bodied interactive learning environments*, which according to Malinverni and Pares (2014) allow the users' movements and actions by the whole body, as mediators of the interactive experience. Only eleven of the reviewed empirical studies (n = 11 studies, 26.8%) included full-bodied

Table 5 Distribution of Reviewed Studies per Embodied Technologies

Type	Technologies	N (%)
Gesture-based environments	• Microsoft Kinect • Nintendo Wii • Web-based camera • Other	19 studies (46.4%) 5 studies (12.2%) 3 studies (7.3%) 3 studies (7.3%) **Total: 30 studies (73.2%)**
Full-body environments	• Mixed reality technologies • Interactive floor	9 studies (21.9%) 2 studies (4.9%) **Total: 11 (26.8%)**

interactive learning environments, as opposed to most of the reviewed studies which included gesture-based learning environments (n = 30 studies, 73.2%). According to the reviewed corpus of studies, most of the full-bodied interactive environments were grounded on mixed reality settings, where students collaborated and interacted in multi-modal learning environments using full-body movements (e.g., Birchfield & Johnson-Glenberg, 2010; Lindgren, Tscholl, Wang, & Johnson, 2016). On the other hand, most of the gesture-based learning environments adopted the Microsoft Xbox Kinect technology (e.g., Altanis, Boloudakis, Retalis, & Nikou, 2013; Anderson & Wall, 2016; Di Tore et al., (2012); Hung, Lin, Fang, & Chen, 2014; Johnson-Glenberg & Hekler, 2013; Si, 2015; Smith, King, & Gonzalez, 2016). Table 5 presents the distribution of the different types of embodied technologies employed in the reviewed studies.

We also focused on the duration of the educational interventions to identify whether there was an emerging trend related to the time span allocated for the implementation of technology-enhanced embodied learning environments. Considering duration, the educational interventions included in the reviewed studies were classified as short-term and long-term duration. Those of short-term duration ranged from a few minutes (e.g., Homer et al., 2014) to 70 min (e.g., Abrahamson, 2013). Those of long-term duration were composed by a set of at least 2 sessions (e.g., Tolentino et al., 2009) up to 26 sessions (e.g., Enyedy, Danish, Delacruz, & Kumar, 2012). According to our analysis, half of the reviewed studies included educational interventions of short-term duration (n = 20 studies, 48.8%), while n = 16 studies included educational interventions of long-term duration (39%) or did not provide specific information on this aspect (n = 5 studies, 12.2%).

4.3 Educational Contexts (RQ2)

The educational contexts in which the technology-enhanced embodied learning environments were used varied substantially in terms of their learning disciplines as well as in the number and age of the students involved. As shown in Table 6, most studies were in the domain of STEM education (27 studies, 65.9%), followed by special

Table 6 Distribution of reviewed studies per domain/discipline and target student ages

Domain/Discipline	Target student ages	N (%)
STEM education • Mathematics (9) • Physics (5) • Biology (4) • Geology (4) • Chemistry (3) • Multiple science topics (2)	K-12 education • Pre-/Primary school (13) • Middle school (7) • High school (7)	27 studies (65.9%)
Special education	K-6 education • Pre-/Primary school (5)	5 studies (12.2%)
Language education	K-6 & High school education • Pre-/Primary school (3) • High school (1)	4 studies (9.7%)
Other • Physical education (2) • Environmental education (1) • Literacy (1) • Music (1)	K-6 & High school education • Pre-/Primary school (4) • High school (1)	5 studies (12.2%)

education (5 studies, 12.2%) and language education (4 studies, 9.7%). Most of the STEM-oriented reviewed studies were focused on mathematics (e.g., Abrahamson, Lee, Negrete, & Gutiérrez, 2014; Abrahamson & Trninic, 2015; Abrahamson et al., 2011; Smith, King, & Hoyte, 2014), physics (e.g., Hung et al., 2014), geology (e.g., Birchfield & Johnson-Glenberg, 2010; Birchfield & Megowan-Romanowicz, 2009), and biology (e.g., Andrade, Danish, & Maltese, 2017). The rest of the studies (5 studies, 12.2%) were related to other domains such as physical education, environmental education, literacy, and music.

The reviewed studies in the domain of STEM education covered the whole spectrum of K-12 system (namely, Pre-/Primary school, Middle school, High school). On the other hand, the reviewed studies in special education, language education, and other domains were mostly contextualized in K-6 settings.

4.4 Research Methods (RQ3)

The empirical studies included in the present review were classified into three main categories: (1) experimental research, (2) design-based research, and (3) other types of research (see also Sheu &Chen, 2014). According to the studies' reported methods, most of them (17 studies, 41.5%) adopted an experimental research design, followed by design-based research (13 studies, 31.7%) and other types of research (11 studies, 26.8%). Table 7 presents the distribution of the reviewed studies per research design.

Most of the experimental research studies were grounded on quasi-experimental designs with pre–post-testing either without a control group or with a nonequiva-

Table 7 Distribution of reviewed studies per research design

Research type	Research design	N (%)
Experimental research	• Quasi-experimental design • Experimental design • Counterbalanced design	11 studies (26.8%) 4 studies (9.8%) 2 studies (4.9%) **Total: 17 studies (41.5%)**
Design-based research	• Multiple case studies • Mixed methods	10 studies (24.4%) 3 studies (7.3%) **Total: 13 studies (31.7%)**
Other types of research	• Pilot/Evaluation studies • Case studies • Exploratory studies • Feasibility studies	5 studies (12.2%) 3 studies (7.3%) 2 studies (4.9%) 1 study (2.4%) **Total: 11 studies (26.8%)**

lent pretest–posttest control group (e.g., Chiu, DeJaegher, & Chao, 2015; Hsiao & Chen, 2016). Most of the design-based research studies (n = 10 studies, 24.4%) were grounded on a series of case studies, representing in most of the cases a set of multiple iterations and evaluations of a given technology-enhanced embodied learning environment (e.g., Anderson & Wall, 2016; Malinverni Schaper, & Pares, 2016). Finally, in the miscellaneous category, most of the studies had the form of pilots for evaluating the impact of technology-enhanced embodied environments on students' learning (e.g., Altanis et al., 2013; Mandanici, Roda, & Canazza, 2016).

In terms of the assessment, the most common measurement was pre–post-testing for evaluating students' learning outcomes (30 studies, 73.2%), followed by interviews with the students (17 studies, 41.5%) and observations via field notes and annotations, or video/audio recordings of the learning sessions (16 studies, 39%). Assessment methods grounded on students' log files and subsequent learning analytics were identified in nine studies (21.9%), while other evaluation methods grounded on students' artifacts, students' and teachers' comments, or teacher reports were noted only in three studies (7.3%). It is also worth mentioning that a total of 13 studies (31.7%) were grounded exclusively on retrospective measurements for the evaluation of technology-enhanced embodied learning, using pre–post-testing (e.g., Birchfield & Johnson-Glenberg, 2010; Jagodziński & Wolski, 2014; Kuo, Hsu, Fang, & Chen, 2014).

4.5 Gains Across Domains of Learning (RQ4)

All reviewed empirical studies reported that technology-enhanced embodied learning environments can have a positive impact on at least one of the three domains of learning: (a) cognitive domain, (b) affective domain, and (c) psychomotor domain. A study would be classified according to all types of learning outcomes reported (e.g., a study reporting outcomes in two domains would be classified two times, one time for each domain). Table 8 provides an overview of the distribution of the learning outcomes by domain, as reported in the reviewed studies.

Cognitive outcomes were the focus in most of the reviewed studies (35 studies, 85.4%), especially those contextualized in STEM education. These studies reported an increase in students' conceptual knowledge on a variety of topics related to mathematics (e.g., Smith et al., 2014), biology (e.g., Andrade et al., 2017), chemistry (e.g., Tolentino et al., 2009), or physics (e.g., Enyedy, Danish, Delacruz & Melissa, 2012). Some of the reviewed studies also reported that students were engaged with effective inquiry learning processes in the technology-enhanced embodied environments employed (Tolentino et al., 2009), or that the technology-enhanced embodied environments were adopted for augmenting the inquiry-based learning process (Anderson & Wall, 2016). However, none of the reviewed studies reported on cognitive outcomes related to students' information searching skills, problem-solving, or metacognition skills (e.g., self-regulation), which are often achieved in inquiry-based learning settings. Finally, only two of the reviewed studies (4.9%) reported on cognitive outcomes related to short-term memory and visual processing (Kourakli et al., 2017) or to students' spatial rotation skills (Tolentino et al., 2009).

Next, a total of 15 studies (36.6%) reported on students' outcome in the affective domain. Most of the reviewed studies reported on students' engagement with the learning process (e.g., Ibánez & Wang, 2015; Lindgren et al., 2016; Tolentino et al., 2009) as well as on students' increase of motivation for participation in the task (e.g., Hwang, Shih, Yeh, Chou, Ma, & Sommool, 2014; Yang, Chen, & Jeng, 2012). Only a limited number of studies reported on the contribution of technology-enhanced embodied learning environments to students' attitudes and dispositions (e.g., Lindgren et al., 2016) or students' social behaviors, such as positive social interactions and collaboration (e.g., Mora-Guiard, Crowell, Pares, & Heaton, 2017; Malinverni et al., 2017).

Finally, only a total of five studies (12.2%) reported data on psychomotor outcomes. These studies were contextualized in the field of special or physical education. These studies reported on the contribution of technology-enhanced embodied learn-

Table 8 Distribution of learning outcomes

Domain	Learning outcomes	N (%)
Cognitive	• Information searching skills • Knowledge acquisition/conceptual understanding • Cognitive skills (e.g., visual and auditory memory, attention, focus) • Problem-solving skills (e.g., analyzing, synthesizing, summarizing, inferring) • Metacognition skills (e.g., self-regulation, self-assessment)	– 35 studies (85.4%) 2 studies (4.9%) – –
Affective	• Motivational outcomes (e.g., interest and curiosity, willingness to learn) • Engagement (e.g., immersion, sense of presence/flow, active participation) • Social behaviors (e.g., positive social interactions, collaboration) • Attitudes and dispositions	6 studies (14.6%) 10 studies (24.4%) 2 studies (4.9%) 1 study (2.4%)
Psychomotor	• Physical skills (e.g., movement, strength, balance, speed, control, coordination, agility)	5 studies (12.2%)

ing environments to students' physical skills, such as movement, strength, balance, speed, object control, coordination, and agility (Altanis et al., 2013; Hsiao & Chen, 2016; Kourakli et al., 2017; Li et al., 2012; Vernadakis et al., 2015).

Overall, most of the reviewed studies provided empirical evidence on the affordances of technology-enhanced embodied learning environments to promote cognitive outcomes. Less attention was given on student outcomes in the affective and psychomotor domains.

4.6 Comparison Studies (RQ5)

This review indicates that 15 studies have examined the learning potential of technology-enhanced embodied learning environments, as compared to other interfaces (3 studies, 7.3%) or forms of instruction (12 studies, 29.3%). Despite the diversity in their research design (e.g., type of embodied learning environments, educational context, assessment), these comparison studies investigated whether there is a significant difference in students' learning outcomes between the experimental group (grounded on embodied learning instruction/interface) and control or comparison group.

According to the results of the reviewed studies, there were only two studies (4.9%) which reported results in favor of the comparison group. For instance, in the study of Jong, Hong, and Yen (2013), the results indicated that kindergarten children, who used a touch-based interface for learning mathematics, outperformed their counterparts in the embodied learning condition who used a gesture-based interface. Likewise, Anderson and Wall (2016) reported that, in contrast to a traditional hands-on inquiry activity, middle school students exhibited lack of engagement and collaboration during an inquiry-based activity structured around a Kinect-based intervention for learning physics. According to their observations, Anderson and Wall (2016) found that the students in the experimental condition were disengaged with the learning aspect of the inquiry as they perceived their interactions with Kinect as a gaming rather than as a learning experience.

In contrast, the rest of the reviewed studies ($n = 13$, 86.7%) reported that students in the embodied learning condition had increased learning gains, compared to students in the control or comparison group. For instance, three of the studies reported that the embodied learning approach could result in better retention when compared to the traditional instructional approach (Kuo, Hsu, Fang, & Chen, 2014; Vernadakis et al., 2015; Yang et al., 2010). Two other studies indicated that students in the experimental group had increased learning gains when compared to their counterparts in the comparison group who used non-embodied interfaces, such as desktop-based computers with a keyboard and a mouse (Hung et al., 2014; Lindgren et al., 2016). Moreover, a set of studies on the evaluation of SMALLab, as a full-body collaborative learning environment, adopted a counterbalanced research design and demonstrated that whenever students were in the SMALLab condition, they learned significantly more.

Overall, most of the reviewed studies reported that the students, who participated in the embodied learning condition, outperformed their counterparts, who participated in the control or comparison group, in terms of their learning outcomes.

5 Discussion, Implications, and Future Studies

There is a widespread assumption that technology-enhanced embodied learning environments, which are grounded on physicality, motion, and interactivity, create new possibilities in the field of education and can promote student learning. The current study reviewed the empirical basis of this assumption by examining 41 empirical studies employing technology-enhanced embodied learning environments in K-12 education, published in relevant journals during the last decade (2008–2017). As part of this review study, we focused on the type of technology-enhanced embodied learning environments utilized, the research methods adopted for their evaluation, and the educational contexts in which they were implemented. In its core, the present review has examined the findings of published empirical studies on technology-enhanced embodied learning environments as they related to (a) students' learning outcomes across the cognitive, affective, and psychomotor domains and (b) the learning effectiveness of embodied learning environments, as compared to other instructional approaches and interfaces. In general, the review revealed positive outcomes in favor of the use of technology-enhanced embodied learning environments in K-12. In the next lines, our findings are synthesized and discussed the form of emerged implications, providing a set of guidelines for future research and practice in the field of embodied learning.

5.1 Design "Open" and Freely Available Applications for Embodied Learning Technologies

First, our analysis indicated that most of the reviewed studies included embodied learning environments grounded on gesture-based technologies as opposed to full-bodied interactive learning environments. Most of the embodied learning environments were based on the use of Kinect cameras. According to Sheu and Chen (2014), this finding could be attributed to the affordability of gesture-based technologies as well as how these technologies can be easily set up and used by educators in typical classroom settings, assuming relevant software is available. While full-bodied learning environments such as SMALLab (e.g., Birchfield, & Johnson-Glenberg, 2010; Johnson-Glenberg, Birchfield, & Sibel, 2009; Tolentino et al., 2009) are based on extensive hardware installations in dedicated rooms (i.e., labs), the newer generation of gesture-based technologies has made embodied learning pedagogy available in the typical classroom. Indeed, gesture-based technologies (e.g., Wii, Kinect, Leap motion) continue to become commercially available while being portable, robust, and affordable. In terms of software, we are facing an explosion of efforts to design gesture-based technologies and develop applications for such technologies, especially in the areas of STEM (e.g., Dahn, Enyedy, & Danish, 2018; Walkington, Chelule, Woods, & Nathan, 2018). Yet, for a wide adoption of embodied learning in education, future work could focus on the design of "open" and freely available applications for portable and affordable gesture-based technologies, which schoolteachers could easily link to units of the everyday curriculum.

5.2 Conduct More Technology Integration Research

Based on this review, many technology-enhanced embodied learning environments were employed in the context of out-of-school activities or in laboratory settings for experimental purposes (e.g., Homer et al., 2014; Lindgren et al., 2016). Fewer technology-enhanced embodied learning environments, mostly in studies of long-term duration, were integrated into the educational curricula, taking the form of an alternative teaching approach (e.g., Anderson & Wall, 2016; Birchfield & Johnson-Glenberg, 2010). For this field to grow and become a more mainstream one, future studies should be more oriented toward the later, i.e., the integration and evaluation of technology-enhanced embodied learning environments in authentic school settings, considering the school curricula, both content-wise and time-wise. Design-based research seems to be the pathway to design, enact, and evaluate such technology and pedagogy innovations in authentic classrooms. Indeed, approximately one-third of the reviewed studies (31.7%) adopted a design-based research approach, as they focused on the design and evaluation of technology-enhanced embodied learning environments; yet more work is needed to address issues of technology integration including opportunities but also difficulties (e.g., classroom orchestration, technological setup, learning design) surrounding embodied learning.

5.3 Extend Embodied Learning Research Beyond STEM

Focusing on the educational contexts in which technology-enhanced embodied learning environments were adopted, most studies were in the domain of STEM education. The prevalence of technology-enhanced embodied learning environments in STEM education could be attributed to the fact that, while STEM-related knowledge and skills can be difficult to acquire, "fundamental STEM knowledge is itself shaped by the embodied nature of the human mind" (Abrahamson & Lindgren, 2014, p. 358). While future studies should continue focusing on the integration and evaluation of technology-enhanced embodied learning environments in STEM education, efforts should also expand to other educational domains and disciplines. For instance, embodied learning appears to have value in the domain of special and inclusive education (Kosmas, Ioannou & Retalis, 2018; Kosmas, Ioannou & Zaphiris, in press; Sheu & Chen, 2014). The review study of Sheu and Chen (2014), which was expanded in adult populations, has indicated that gesture-based technologies could have a pivotal role in supporting learners with both physical and cognitive difficulties to conquer daily life skills. They have concluded that gesture-based technologies, and mainly Wii, have significant implications in special education for disabled individuals and those with special needs. In this spirit, technology-enhanced embodied learning environments might enable the creation of inclusive educational environments providing equal learning opportunities and tools for both mainstream and special education K-12 students.

5.4 In Situ Measurements

The assessment techniques employed in the reviewed articles were characterized by the frequent use of retrospective pre–post-self-assessment methods, which requires reflection in relation to the theoretical groundings of embodied cognition. For instance, a total of 13 studies (31.7%) evaluated embodied learning grounded exclusively on retrospective measurements, using pre–post questionnaires (e.g., Birchfield & Johnson-Glenberg, 2010; Jagodziński & Wolski, 2014; Kuo, Hsu, Fang, & Chen, 2014). This finding is also aligned with the previous review of Maliverni and Pares (2014) who argued that such a retrospective assessment is contradictory with the very nature of embodied learning, given that it fails to capture the situated construction of meaning and the bodily-based knowledge, as this is produced in situ. Future studies should take into consideration the use of in situ measurements, such as log files capturing students' movements, video- and audio-recording capturing student' utterance and gestural actions, as well as task-based interviews providing useful insights on how the embodied learning process is unfolded. Such efforts could also result in an evidence-based development of a coding scheme, providing a set of indicators for capturing and analyzing the embodied learning phenomenon. On the other hand, future research could benefit from the development and validation of psychometric instruments for capturing the embodied phenomenon, i.e., the perceived embodied degree of the learning experience.

5.5 Beyond Conceptual Understanding

Most of the reviewed studies focused on the examination of students' cognitive outcomes, namely, conceptual understanding in the context of STEM education. This finding could be attributed to the fact that, despite the curriculum reform efforts observed during the last decades, students' preparation for high-stakes testing puts an emphasis on conceptual understanding rather than on promoting other types of learning outcomes (Falk & Drayton, 2004). Another plausible explanation could be current assessment practices which, similarly, emphasize conceptual understanding (NRC, 2011) and fail to assess other aspects of learning. Our findings indicate a need for further investigation of the potential of technology-enhanced embodied learning environments to facilitate students' learning beyond conceptual understanding, considering learning outcomes such as problem-solving or metacognition skills as well as outcomes in the affective and psychomotor domains. Besides, as argued by Li and Tsai (2013), in order to explore the advantages of an innovative learning approach over other instructional methods, student outcomes should be compared extensively and holistically.

5.6 Address Methodological Concerns in Experimental Designs

A significant corpus of the empirical studies was grounded on experimental research, adopting a pre–post research design in order to gather empirical evidence for supporting the learning effectiveness of technology-enhanced embodied learning environments. These experiments examined the potential of technology-enhanced embodied learning environments as compared to other forms of instruction and interfaces. We have identified 15 empirical studies, with 13 of them (86.7%) reporting that students in the embodied learning condition had increased learning gains, when compared to students participating in the control/comparison group. However, these promising results in favor of embodied learning should be treated with caution, considering at least two main methodological concerns related to their: (a) sampling and (b) research design.

First, in many of the reviewed studies, the number of participants was relatively small. Therefore, as reported by some researchers, (a) the statistical power was not always sufficient for the analyses conducted (Johnson-Glenberg, Birchfield, Megowan-Romanowicz, & Snow, 2015), (b) the samples were not sufficient to verify and generalize the positive findings identified (Hwang et al., 2014), and (c) there was not enough statistical power to investigate aptitude by treatment interactions, taking, for instance, into account the role of students' prior knowledge (Johnson-Glenberg et al., (2014a, b, 2015). Future, experimental studies should make use of larger samples, which would allow the generalizability of the findings as well as the investigation of aptitude by treatment interactions (McLeod, Cronbach, & Snow, 1978), taking into consideration a set of additional students' characteristics (e.g., digital skills, attitudes toward computers).

Second, many experimental studies took place in complex educational settings, which made it difficult to identify the driving forces behind the observed learning gains. Researchers in a set of comparison studies investigating the learning effectiveness of the SMALLab have reported that they could not define if their positive findings were attributed to the embodied approach, to student collaboration, to the technological affordances, to the experienced novelty effect, or even to the interaction of all these factors. Future studies should therefore be grounded on research designs that allow more firm explanations on the learning effectiveness of technology-enhanced embodied learning environments. Future studies, for instance, could compare the learning impact of gesture-based learning environments with full-bodied ones; researchers could retain collaboration, embodied technologies, and novelty in both conditions and isolate the impact of embodiment, given that full-body interactive learning environments are considered as more embodied. On a different vein, future studies could compare the effectiveness of digital and not-digital embodied learning environments (see Tran, Smith, & Buschkuehl, 2017, for a relevant discussion). In this case, researchers could retain embodiment, collaboration, and novelty in both conditions and isolate the digital aspect for investigating the impact of motion-based technologies.

6 Limitations

The papers included in the present review study were limited to journal articles indexed in the four databases (Education Research Complete [via EBSCO], ERIC, JSTOR, and Scopus) as well as in Google Scholar, or were identified via the ancestry method, and were published from 2008 to 2017. Future reviews could extend this review and include conference papers retrieved from relevant databases (e.g., ACM, IEEE). Despite the relatively limited number of studies included in this review study, we have followed a well-designed sampling process, grounded on a set of carefully selected criteria, in order to result in a systematic and coherent review study. Finally, future review studies could also be expanded on the use of embodied learning environments in higher education, by adult populations, and in other domains (e.g., medical training, physical therapy, sports, and exercise science).

7 Conclusions

To sum up, research on technology-enhanced environments for embodied learning is a nascent but growing research area. This review has examined the literature on K-12 empirical research employing technology-enhanced embodied learning environments. In general, the review revealed positive learning outcomes across the cognitive, affective, and psychomotor domains, linked to the use of technology-enhanced embodied learning environments in K-12. The review indicated that embodied learning work seems to focus primarily on the promotion of cognitive outcomes in STEM education. Future research could be expanded into more types of learning outcomes. Also, future research should be based on more objective and in situ measurements, rather than retrospective pre–post-testing, which is incongruent with the epistemological grounds of embodied cognition. At the same time, research should investigate the effectiveness of the technology-enhanced embodied learning environments, as compared to other forms of instruction and interfaces, using larger samples to allow for firm statistical analyses and generalizable conclusions. Finally, future studies should be grounded on research designs that enable empirical substantiation on the positive contribution of technology-enhanced embodied learning environments, by controlling the effects of other variables such as student collaboration.

Acknowledgements This work is part of the project that has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 739578 (RISE-Call:H2020-WIDESPREAD-01-2016-2017-TeamingPhase2) and the government of the Republic of Cyprus through the Directorate General for European Programmes, Coordination and Development.

References

*Articles in the Review Corpus

*Abrahamson, D. (2013). Building educational activities for understanding: An elaboration on the embodied-design framework and its epistemic grounds. *International Journal of Child-Computer Interaction*, *2*(1), 1–16. https://doi.org/10.1016/j.ijcci.2014.07.002.

*Abrahamson, D., Lee, R. G., Negrete, A. G., & Gutiérrez, J. F. (2014). Coordinating visualizations of polysemous action: Values added for grounding proportion. *ZDM Mathematics Education*, *46*(1), 79–93. https://doi.org/10.1007/s11858-013-0521-7.

*Abrahamson, D., & Trninic, D. (2015). Bringing forth mathematical concepts: signifying sensorimotor enactment in fields of promoted action. *ZDM Mathematics Education*, *47*(2), 295–306. https://doi.org/10.1007/s11858-014-0620-0.

Abrahamson, D., & Lindgren, R. (2014). Embodiment and embodied design. In *The Cambridge Handbook of the Learning Sciences, Second Edition* (pp. 358–376). https://doi.org/10.1017/CBO9781139519526.022.

*Abrahamson, D., & Sánchez-García, R. (2016). Learning is moving in new ways: The ecological dynamics of mathematics education. *Journal of the Learning Sciences*, *25*(2), 203–239. https://doi.org/10.1080/10508406.2016.1143370.

*Abrahamson, D., Trninic, D., Gutiérrez, J. F., Huth, J., & Lee, R. G. (2011). Hooks and shifts: A dialectical study of mediated discovery. *Technology, Knowledge and Learning*, *16*(1), 55–85. https://doi.org/10.1007/s10758-011-9177-y.

*Altanis, G., Boloudakis, M., Retalis, S., & Nikou, N. (2013). Children with motor impairments play a Kinect learning game: First findings from a pilot case in an authentic classroom environment. *Interaction Design and Architecture(s) Journal - IxD&A*, *19*(19), 91–104.

*Anderson, J. L., & Wall, S. D. (2016). Kinecting physics: Conceptualization of motion through visualization and embodiment. *Journal of Science Education and Technology*, *25*(2), 161–173. https://doi.org/10.1007/s10956-015-9582-4.

*Andrade, A., Danish, J., & Maltest, A. (2017). A measurement model of gestures in an embodied learning environment: Accounting for temporal dependencies. *Journal of Learning Analytics*, *4*(3), 18–45. https://doi.org/10.18608/jla.2017.43.3.

Antle, A. N., Corness, G., & Droumeva, M. (2009). What the body knows: Exploring the benefits of embodied metaphors in hybrid physical digital environments. *Interacting with Computers, 21*(1–2), 66–75. https://doi.org/10.1016/j.intcom.2008.10.005.

Antle, A. N. (2013). Research opportunities: Embodied child-computer interaction. *International Journal of Child-Computer Interaction, 1*(1), 30–36. https://doi.org/10.1016/j.ijcci.2012.08.001.

Baker, E. L., & Mayer, R. E. (1999). Computer-based assessment of problem solving. *Computers in Human Behavior, 15*(3–4), 269–282.

Barsalou, L. W. (2010). Grounded cognition: Past, present, and future. *Topics in cognitive science, 2*(4), 716–724.

*Birchfield, D., & Megowan-Romanowicz, C. (2009). Earth science learning in Smallab: A design experiment for mixed reality. *International Journal of Computer-Supported Collaborative Learning*, *4*(4), 403–421. https://doi.org/10.1007/s11412-009-9074-8.

*Birchfield, D., & Johnson-Glenberg, M. (2010). A next gen Interface for embodied learning. *International Journal of Gaming and Computer-Mediated Simulations*, *2*(1), 49–58. https://doi.org/10.4018/jgcms.2010010105.

*Birchfield, D., Thornburg, H., Megowan-Romanowicz, M. C., Hatton, S., Mechtley, B., Dolgov, I., & Burleson, W. (2008). Embodiment, multimodality, and composition: Convergent themes across HCI and education for mixed-reality learning environments. *Advances in Human-Computer Interaction*, *2008*, 1–19. https://doi.org/10.1155/2008/874563.

Bloom, B. (1956). *Taxonomy of Educational Objectives – The Cognitive Domain*. New York: Donald McKay.

*Chiu, J. L., Dejaegher, C. J., & Chao, J. (2015). The effects of augmented virtual science laboratories on middle school students' understanding of gas properties. *Computers and Education*, *85*, 59–73. https://doi.org/10.1016/j.compedu.2015.02.007.

Cooper, H. M. (1982). Scientific guidelines for conducting integrative research reviews. *Review of Educational Research, 52*(2), 291–302. https://doi.org/10.3102/00346543052002291.

Dahn, M., Enyedy, N., & Danish, J. (2018). *How teachers use instructional improvisation to organize science discourse and learning in a mixed reality environment* (pp. 72–79). London, UK: International Society of the Learning Sciences (ISLS).

*Di Tore, S., Aiello, P., Palumbo, C., Vastola, R., Raiola, G., D'Elia, F., … Sibilio, M. (2012). Sensory motor interaction in virtual environment to promote teaching-learning process. *Problems of Education in the 21st Century*, *42*, 29–37.

*Enyedy, N., Danish, J. A., & DeLiema, D. (2015). Constructing liminal blends in a collaborative augmented-reality learning environment. *International Journal of Computer-Supported Collaborative Learning*, *10*(1), 7–34. https://doi.org/10.1007/s11412-015-9207-1.

*Enyedy, N., Danish, J. A., Delacruz, G., & Kumar, M. (2012). Learning physics through play in an augmented reality environment. *International Journal of Computer-Supported Collaborative Learning*, *7*(3), 347–378. https://doi.org/10.1007/s11412-012-9150-3.

Falk, J., & Drayton, B. (2004). State testing and inquiry-based science: Are they complementary or competing reforms? *Journal of Educational Change, 5*(4), 345–387. https://doi.org/10.1007/s10833-004-1069-7.

Gagné, R. M. (1977). *The conditions of learning*. New York: Holt, Rinehart & Winston.

Goldinger, S. D., Papesh, M. H., Barnhart, A. S., Hansen, W. A., & Hout, M. C. (2016). The poverty of embodied cognition. *Psychonomic Bulletin & Review, 23*(4), 959–978. https://doi.org/10.3758/s13423-015-0860-1.

*Homer, B. D., Kinzer, C. K., Plass, J. L., Letourneau, S. M., Hoffman, D., Bromley, M., … Kornak, Y. (2014). Moved to learn: The effects of interactivity in a Kinect-based literacy game for beginning readers. *Computers and Education*, *74*, 37–49. https://doi.org/10.1016/j.compedu.2014.01.007.

*Hsiao, H. S., & Chen, J. C. (2016). Using a gesture interactive game-based learning approach to improve preschool children's learning performance and motor skills. *Computers and Education*, *95*, 151–162. https://doi.org/10.1016/j.compedu.2016.01.005.

*Hung, I. C., Lin, L. I., Fang, W. C., & Chen, N. S. (2014). Learning with the body: An embodiment-based learning strategy enhances performance of comprehending fundamental optics. *Interacting with Computers*, *26*(4), 360–371. https://doi.org/10.1093/iwc/iwu011.

*Hwang, W. Y., Shih, T. K., Yeh, S. C., Chou, K. C., Ma, Z. H., & Sommool, W. (2014). Recognition-based physical response to facilitate EFL learning. *Educational Technology and Society*, *17*(4), 432–445.

*Ibánez, J. de J. L. G., & Wang, A. I. (2015). Learning recycling from playing a Kinect game. *International Journal of Game-Based Learning*, *5*(3), 25–44. https://doi.org/10.4018/IJGBL.2015070103.

*Jagodziński, P., & Wolski, R. (2014). The examination of the impact on students' use of gestures while working in a virtual chemical laboratory for their cognitive abilities. *Problems of Education in the 21st Century*, *61*, 46–57.

Johnson, L., Adams, S., & Cummins, M. (2012). *The 2012 horizon report*. Austin, Texas: The New Media Consortium.

*Johnson-Glenberg, M. C., Hekler, E. (2013). An embodied, motion-capture exergame teaching nutrition and MyPlate. *Games for Health Journal*, *2*, 354–361.

*Johnson-Glenberg, M. C., Birchfield, D. A., Tolentino, L., & Koziupa, T. (2014). Collaborative embodied learning in mixed reality motion-capture environments: Two science studies. *Journal of Educational Psychology*, *106*(1), 86–104. https://doi.org/10.1037/a0034008.

*Johnson-Glenberg, M. C., Birchfield, D. A., Megowan-Romanowicz, C., & Snow, E. L. (2015). If the gear fits, spin it! *International Journal of Gaming and Computer-Mediated Simulations*, *7*(4), 40–65. https://doi.org/10.4018/IJGCMS.2015100103.

*Johnson-Glenberg, M. C., Birchfield, D., & Usyal, S. (2009). *SMALLab*: virtual geology studies using embodied learning with motion, sound, and graphics. *Educational Media International*, *46*(4), 267–280. https://doi.org/10.1080/09523980903387555.

*Johnson-Glenberg, M. C., Savio-Ramos, C., & Henry, H. (2014). "Alien Health": A nutrition instruction exergame using the Kinect sensor. *Games for Health Journal*, *3*(4), 241–251. https://doi.org/10.1089/g4h.2013.0094.

Johnson-Glenberg, M. C., Megowan-Romanowicz, C., Birchfield, D. A., & Savio-Ramos, C. (2016). Effects of embodied learning and digital platform on the retention of physics content: Centripetal force. *Frontiers in psychology, 7,* 1819.

Johnson-Glenberg, M. C., & Megowan-Romanowicz, C. (2017). Embodied science and mixed reality: How gesture and motion capture affect physics education. *Cognitive research: principles and implications, 2*(1), 24.

*Jong, J. T., Hong, J. C., & Yen, C. Y. (2013). Persistence temperament associated with children playing math games between touch panel and embodied interaction. *Journal of Computer Assisted Learning*, *29*(6), 569–578. https://doi.org/10.1111/jcal.12017.

Kraiger, K., Ford, J. K., & Salas, E. (1993). Application of cognitive, skill-based, and affective theories of learning outcomes to new methods of training evaluation. *Journal of Applied Psychology, 78*(2), 311.

Kosmas, P., Ioannou, A., & Retalis, S. (2018). Moving bodies to moving minds: A study of the use of motion-based games in special education. *TechTrends*, 1–8. https://doi.org/10.1007/s11528-018-0294-5.

Kosmas, P., Ioannou, A., & Zaphiris, P. (in press). Implementing embodied learning in the classroom: Effects on children's memory and language skills. Educational Media International. https://doi.org/10.1080/09523987.2018.1547948.

*Kourakli, M., Altanis, I., Retalis, S., Boloudakis, M., Zbainos, D., & Antonopoulou, K. (2017). Towards the improvement of the cognitive, motoric and academic skills of students with special educational needs using Kinect learning games. *International Journal of Child-Computer Interaction*, *11*, 28–39. https://doi.org/10.1016/j.ijcci.2016.10.009.

Krathwohl, D. R., Anderson, L. W., Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., … Wittrock, M. C. (2002). *A Taxonomy For Learning, Teaching, And Assessing: A Revision Of Bloom's Taxonomy Of Educational Objectives*. *New York Longman*. New York, NY: Addison Wesley Longman. https://doi.org/10.1207/s15430421tip4104_2.

*Kuo, F. R., Hsu, C. C., Fang, W. C., & Chen, N. S. (2014). The effects of embodiment-based TPR approach on student English vocabulary learning achievement, retention and acceptance. *Journal of King Saud University - Computer and Information Sciences*, *26*(1), 63–70. https://doi.org/10.1016/j.jksuci.2013.10.003.

*Li, K., Lou, S., Tsai, H., & Shih, R. (2012). The effects of applying game-based learning to webcam motion sensor games for autistic student's sensory integration. *Tojet*, *11*(4), 451–459. Retrieved from http://www.tojet.net/articles/v11i4/11446.pdf.

Li, M.-C., & Tsai, C.-C. (2013). Game-based learning in science education: A review of relevant research. *Journal of Science Education and Technology, 22*(6), 877–898. https://doi.org/10.1007/s10956-013-9436-x.

*Lindgren, R., Tscholl, M., Wang, S., & Johnson, E. (2016). Enhancing learning and engagement through embodied interaction within a mixed reality simulation. *Computers and Education*, *95*, 174–187. https://doi.org/10.1016/j.compedu.2016.01.001.

*Malinverni, L., Mora-Guiard, J., Padillo, V., Valero, L., Hervás, A., & Pares, N. (2017). An inclusive design approach for developing video games for children with Autism Spectrum Disorder. *Computers in Human Behavior*, *71*, 535–549. https://doi.org/10.1016/j.chb.2016.01.018.

Malinverni, L., & Pares, N. (2014). Learning of abstract concepts through full-body interaction: A systematic review. *Educational Technology & Society, 17*(4), 100–116. https://doi.org/10.2307/jeductechsoci.17.4.100.

*Malinverni, L., Schaper, M. M., & Pares, N. (2016). An evaluation-driven design approach to develop learning environments based on full-body interaction. *Educational Technology Research and Development*, *64*(6), 1337–1360. https://doi.org/10.1007/s11423-016-9468-z.

*Mandanici, M., Roda, A., & Canazza, S. (2016). The harmonic walk: An interactive physical environment to learn tonal melody accompaniment. *Advances in Multimedia*, *2016*. https://doi.org/10.1155/2016/4027164.

McLeod, D. B., Cronbach, L. J., & Snow, R. E. (1978). *Aptitudes and Instructional Methods: A Handbook for Research on Interactions*. *Journal for Research in Mathematics Education* (Vol. 9). New York: Irvington. https://doi.org/10.2307/748778.

Melcer, E. F., & Isbister, K. (2016, May). Bridging the physical divide: A design framework for embodied learning games and simulations. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (pp. 2225-2233). ACM.

*Mora-Guiard, J., Crowell, C., Pares, N., & Heaton, P. (2017). Sparking social initiation behaviors in children with Autism through full-body Interaction. *International Journal of Child-Computer Interaction*, *11*, 62–71. https://doi.org/10.1016/j.ijcci.2016.10.006.

Nguyen, D. J., & Larson, J. B. (2015). Don't forget about the body: Exploring the curricular possibilities of embodied pedagogy. *Innovative Higher Education, 40*(4), 331–344. https://doi.org/10.1007/s10755-015-9319-6.

NRC (2011). *Learning science through computer games and simulations*. (H. M., Honey M. A., Ed.), *Studies in Science Education*. Washington, DC: The National Academies Press.

Sheu, F. R., & Chen, N. S. (2014). Taking a signal: A review of gesture-based computing research in education. *Computers & Education, 78,* 268–277. https://doi.org/10.1016/j.compedu.2014.06.008.

*Si, M. (2015). A virtual space for children to meet and practice Chinese. *International Journal of Artificial Intelligence in Education*, *25*(2), 271–290. https://doi.org/10.1007/s40593-014-0035-7.

Skulmowski, A., & Rey, G. D. (2018). Embodied learning: introducing a taxonomy based on bodily engagement and task integration. *Cognitive Research: Principles and Implications, 3*(1), 6. https://doi.org/10.1186/s41235-018-0092-9.

*Smith, C., King, B., & Gonzalez, D. (2016). Using multimodal learning analytics to identify patterns of interactions in a body-based mathematics activity. *Journal of Interactive Learning Research*, *27*(4), 355–379.

*Smith, C. P., King, B., & Hoyte, J. (2014). Learning angles through movement: Critical actions for developing understanding in an embodied activity. *Journal of Mathematical Behavior*, *36*, 95–108. https://doi.org/10.1016/j.jmathb.2014.09.001.

*Tolentino, L., Birchfield, D., Megowan-Romanowicz, C., Johnson-Glenberg, M. C., Kelliher, A., & Martinez, C. (2009). Teaching and learning in the mixed-reality science classroom. *Journal of*

Science Education and Technology, *18*(6), 501–517. https://doi.org/10.1007/s10956-009-9166-2.

Tran, C., Smith, B., & Buschkuehl, M. (2017). Support of mathematical thinking through embodied cognition: Nondigital and digital approaches. *Cognitive Research: Principles and Implications, 2*(1), 16. https://doi.org/10.1186/s41235-017-0053-8.

*Vernadakis, N., Papastergiou, M., Zetou, E., & Antoniou, P. (2015). The impact of an exergame-based intervention on children's fundamental motor skills. *Computers and Education*, *83*, 90–102. https://doi.org/10.1016/j.compedu.2015.01.001.

Walkington, C., Chelule, G., Woods, D., & Nathan, M. J. (2018). *Collaborative gesture as a case of distributed mathematical cognition gesture as simulation action research questions*. London, UK: International Society of the Learning Sciences (ISLS) (pp. 552–559).

Wouters, P., Van der Spek, E. D., & Van Oostendorp, H. (2009). Current practices in serious game research: A review from a learning outcomes perspective. In *Games-based learning advancements for multi-sensory human computer interfaces: techniques and effective practices* (pp. 232–250). IGI Global.

*Yang, J. C., Chen, C. H., & Jeng, M. C. (2010). Integrating video-capture virtual reality technology into a physically interactive learning environment for English learning. *Computers & Education*, *55*(3), 1346–1356.

Chapter 9
Review of Augmented Reality in Education: Situated Learning with Digital and Non-digital Resources

Yun Wen and Chee-Kit Looi

1 Introduction

The *Horizon Report* for 2012 (NMC, 2012) predicted that augmented reality (AR) technology would be widespread in K-12 education setting within 4–5 years. This technology has gained much attention in recent years, and the use of AR in education has become prevalent in numerous applications. AR, together with the term mixed reality, is used to describe computer-supported environments where both physical objects and virtual objects are used (Milgram & Kishino, 1994). A large and growing body of literature has reported affordances and effectiveness of the use of AR in different scenarios. Building on this base, a series of literature reviews have been carried out to discuss status, challenges, and trends of AR used in educational settings (e.g., Akçayır & Akçayır, 2017; Bacca et al., 2014; Wu, Lee, Chang, & Liang, 2013).

Wu et al. (2013), for instance, identified five features and affordances of AR systems. According to their review research, AR could enable (1) learning content in 3D perspective; (2) ubiquitous, collaborative, and situated learning; (3) learners' sense of presence, immediacy, and immersion; (4) visualizing the invisible; and (5) bridging formal and informal learning. However, these features are not unique to AR applications. To further explore the potential of AR in education, we need to focus on the characteristics of AR in education that differentiate it from other technological systems.

A key characteristic of AR mentioned in the *Horizon Report* 2012 (Johnson, Adams, Cummins, & Estrada, 2012) is about its ability to respond to user input. This interactivity can help learners to link what they are observing or manipulating to their prior knowledge, and through this construct new understanding. In this sense,

---

Y. Wen · C.-K. Looi (✉)
National Institution of Education, Singapore, Singapore
e-mail: cheekit.looi@nie.edu.sg

Y. Wen
e-mail: yun.wen@nie.edu.sg

P. Díaz et al. (eds.), *Learning in a Digital World*, Smart Computing and Intelligence, https://doi.org/10.1007/978-981-13-8265-9_9

augmented virtuality is a variation of AR, in which a virtual environment serves as the backdrop, while virtual data is blended in and superimposed. Akçayır and Akçayır (2017) indicated in their recent review paper that the combination of virtual and real objects in a real setting is the unique feature of AR. Therefore, in this review paper, we will further discuss and categorize its educational affordances, based on this unique feature of AR. AR adds digital elements to real-world non-digital settings in a planned and synergistic way to support different forms of learning.

There has been empirical work and evidence of efficacy in using AR to understand science phenomena that are not easy to explain through direct instruction such as Bernoulli's principle (Yoon, Anderson, Lin, & Elinich, 2017) or Newtonian laws of physics (Cheng & Tsai, 2013). AR has also been deployed to enhance students' memory and learning vocabulary (Liu, 2009) as well as to improve students' learning motivation. There also have been a number of research studies that demonstrate cognitive and affective effects of AR on learning. However, after analyzing 32 studies published in 6 indexed journals between 2003 and 2013, Bacca et al. (2014) summarized that the major learning effectiveness was reported by focusing on learning gains in terms of pre- and posttest results or learning motivations.

Instead of merely providing novel and interesting approaches to convey information, the potential of AR-based learning will be uncovered through investigating how and why AR should be used to promote learning effectively. In particular, we want to answer these questions:

- What are the main fields of studies that AR applied to?
- What are the theoretical and analytical foundations mentioned in the studies?
- What are the pedagogical approaches or strategies integrated into AR applications?

Thus, we conducted a review study to seek answers to these questions. In doing the review, we will pay more attention to those studies in which theoretical foundations of learning and AR-based learning processes were discussed. Meanwhile, as the effect of AR techniques on learning depends on the innovative and imaginative design of pedagogical applications (Cabero & Barroso, 2016; Wen, 2018), a systematic review will be carried out to unpack the pedagogical approaches or strategies adopted in the existing studies.

The rest of this paper is organized as follows. Section 2, we propose a framework to classify the relevant studies of AR into different categories. The method and process of this review are introduced in Sect. 3. Section 4 presents the results of the review. The last two sections provide a discussion and conclusions, respectively.

2 Classifying AR Applications in Terms of Educational Affordances

AR is not limited to a particular device. Depending on the recognition technique, AR systems were divided into two categories by Cheng and Tsai (2013). They are *image-based* and *location-based AR*, regardless of what hardware or software is used.

According to them, the image-based AR is focused on image recognition techniques that determine the position of physical objects in real environment. The image-based AR can be further divided into two subcategories: (1) marker-based AR with specific labels, such as Quick Response (QR) codes; and (2) markerless tracking with natural graphic recognition. In contrast to image-based AR, location-based AR uses position data such as data from wireless network or Global Positioning System (GPS) to identify the location, and then superimpose computer-generated information. This sort of technique-oriented categorization is useful in the early days when AR applications are relatively new to most people. With the wide use of AR, instead of recognition techniques, we suggest reclassifying AR applications by considering *whether they enable context-aware learning experiences*.

The concept of context-aware learning is not new in the field of mobile learning. The term *context-aware* was first defined by Schilit, Adams, and Want (1994). According to them, context is "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user" (Dey, 2001, p. 5). Those handheld devices with sensors have enabled context-aware learning experiences that complement classroom pedagogy by involving the context in the learning process (Laine, Nygren, Dirin, & Suk, 2016). A context-aware learning design can detect and act upon changes in the learner's context (e.g., location, environment, state of body and mind, social group), and provide learning content relevant to the learner's situation (Laine, 2012). A typical scenario of context-aware learning can be a problem-based learning environment where the learner solves contextually relevant problems (Hmelo-silver & Barrows, 2006; Laine et al., 2016).

Therefore, the concept of context-aware learning is broader than the concept of location-based learning which merely emphasizes the affordances of mobile devices to deliver information about the physical environment. Apart from location-based AR applications for out-of-class use, those AR applications on drama or games (both digital and physical) all belong to the category of context-aware AR applications. The rest of the applications (whether they are AR-based books or simulations) are attributed to the category of context-independent AR applications if the context is not emphasized in the AR system or activity design.

Even though context-aware learning enables situated, authentic, and personalized learning experiences, it cannot guarantee the enhancement of learning effect, as learners may participate passively in the learning process and activities. Hence, one more dimension is included to categorize AR applications in learning: deep learning and surface learning. Marton and Säljö (1976) introduced the idea of deep and surface approaches to learning as they distinguished the manner in which students approached reading. The subsequent studies built upon their findings and demonstrated that these different approaches emerge in diverse learning tasks. In this study, the deep and surface learning do not refer to fixed learning styles of learners. Deep learning implies the orientation of knowledge transforming with characteristics such as synthesis and evaluation, and a personal commitment to learn the material (Biggs, 1987; Floyd, Harrington, & Santiago, 2009). Deep learning (Pellegrino & Hilton, 2012) implies the development of new ways of acting, thinking, and talking, as new mental functions, and skills which are transferable to other contexts of application. Surface learning, on the contrary, is associated more with memorizing, reciting, or regurgitating what cannot be applied in different scenarios. In this study, we take deep learning to refer to intentional deep learning as the educational goal of the activity in which AR design is embedded, as against "surface learning" in which there is no explicit intention of fostering deep learning. Accordingly, AR application studies can be classified into four categories: context-independent + surface learning; context-independent + deep learning; context-aware + surface learning; and context-aware + deep learning.

3 Review Methods

This review paper aims to provide insights into AR design in educational contexts, by focusing on discussing how and why AR technology can be used to promote learning effectively. To answer the questions, we selected scientific articles on the educational uses of AR, published in journals that are indexed in the SSCI database. We used two well-known online research databases related to education and technology (ERIC and the ACM Digital Library), searching with the query string: ("augmented reality" OR "mixed reality") AND (education), we obtained a total of 356 journal papers. Till April 10, 2018, the search of the journal papers yielded 356 results. In the first round of screening, we eliminated studies that did not involve a concrete intervention (e.g., technical development papers or literature reviews). Then in the second round of screening, we eliminated duplicates that the papers from similar authors discussing the same application in similar settings, and excluded the studies that only provided users' perceptions toward the system use without a discussion about learning effect. And also, in this process, we added eight more relevant papers to the pool via scanning references cited in the previously selected papers. As a result, 57 papers were identified as eligible articles for the further analysis.

The analyses of this study consist of two steps. In the first step, we classified all the 57 studies into 4 categories in terms of the framework of organizing AR applications proposed in Sect. 2. Then, in the second step, based on the studies we found in the four quadrants, we did content analysis to answer the questions presented in the introduction section on the main fields of studies that AR applied to; the theoretical and analytical foundations mentioned in the studies; and the pedagogical approaches or strategies integrated in AR applications.

4 Review Results

4.1 Main Fields of Study That AR Has Been Applied to

In considering the categories to organize the AR papers, we first consider the education levels, namely, pre-school, K-12, college or university education, and professional and workplace learning. We consider special education as an area that lends itself to exploiting AR; hence, we include it as a category. Several papers fall into K-12 education; hence, we consider the subject domain as a further category breakdown into mathematics, sciences, and the category of language learning and social studies. Hence, we settle on the classification categories for the main fields of studies of AR: (1) kindergarten, (2) K12_Mathematics, (3) K12_Science, (4) K12_Language learning and other social studies, (5) university, (6) professional training/workplace learning, and (7) special education.

In all the quadrants, the number of eligible studies about K12 science education is obviously higher than in other subject areas (see Table 1). Some studies made use of AR to improve students' context-aware learning experiences (e.g., Enyedy, Danish, & DeLiema, 2015; Laine et al., 2016), while others are focused on presenting scientific elements essential to understanding a concept or phenomenon in diverse ways. Studies in which AR was used in K12 mathematics learning were concentrated on taking use of AR to improve students' spatial abilities that are characterized as being able to construct and maintain high-quality internal spatial representations and to accurately transform these representations (Salinas & Pulido, 2017). Researchers in mathematics education believed that learning to think spatially had an important potential of AR in mathematic learning, but contextual information was less taken into consideration in their system or activity design.

There are a growing number of the use of AR in pre-school education and workplace learning. In addition to comparing AR-supported picture books with traditional picture books, some researchers explored the design of an AR-infused robot system to enhance children's engagement in dramatic play activities (Han et al., 2015). Considering the need of direct communication channel over distance to share specific situation and details, Pejoska, Bauters, Purma, & Leinonen (2016) designed a social AR prototype for asking and providing guidance in a context-reliant workplace.

As shown in Table 1, among the 57 analyzed papers, less than half of them (22 of 57) were classified into the category of context-aware. Nevertheless, the majority of these context-aware studies (21 of 24) were associated with deep learning. On the contrary, most of the context-independent studies (22 of 33) concentrated on surface learning. The findings suggested that there is no causal relation between context and deep learning. In other words, presenting learning information through AR mode may help learners transform the learning information from short-term to long-term memory, but cannot ensure that deep learning takes place. Deep learning is more likely to happen when students face a problem or question that creates cognitive conflicts derived from social interaction with peers. When attempting to use AR

Table 1 Distribution of the main fields of studies that AR has been applied to

Subjects and levels	Context-independent		Context-aware	
	Surface learning	Deep learning	Surface learning	Deep learning
	Quadrant I	Quadrant II	Quadrant III	Quadrant IV
Kindergarten	2	1		1
K12_Mathematics	4	2		
K12_Science	7	5	2	9
K12_Language learning and other social studies		1	1	3
University	6	2		4
Training/workplace learning	2			3
Special education	1			
Sum	**22**	**11**	**3**	**21**
	33		**24**	

for enabling context-aware learning experiences, educational designers are usually inclined to set learning goals beyond content knowledge acquisition or memory retention.

4.2 The Theoretical and Analytic Foundations

With respect to the theoretical and analytic foundations for AR applications in teaching and learning, the results showed that many studies lacked an explicit theoretical framework (see Table 2). According to our analysis, there were differences among the theoretical and analytical foundations adopted or proposed in the studies of each quadrant. These theories and frameworks, and the studies which referenced or used them, are presented in Table 2. The theories regarding the role of multimedia in learning, such as cognitive theory of multimedia learning (Mayer, 2009) and multiple resource theory (Wickens, Hollands, Banbury, & Parasuraman, 2016), were used in the studies of Quadrant I. They suggested that the AR technique served as a valuable learning scaffold by enabling learners to visualize details, and to recognize and make sense of hidden information. Furthermore, the AR technique provided students opportunities to experience information through visual, spatial, and sensorimotor feedback in response to interface manipulations (Hung, Chen, & Huang, 2017). That may be the reason why the studies in Quadrant I concentrated more on those difficult and important knowledge points of a specific subject.

Table 2 The theoretical and analytic foundations in each quadrant

Theoretical and analytic foundations	Context-independent		Context-aware	
	Quadrant I	Quadrant II	Quadrant III	Quadrant IV
Multiple resource theory (Wickens et al. 2016)	Hung et al. (2017)			
Cognitive theory of multimedia learning (Mayer, 2009)	Montoya, Díaz, and Moreno (2017)			
Knowledge integration (Linn & Eylon, 2011)		Chao, Chiu, DeJaegher, and Pan (2016)		
Situated learning theory			Chen and Tsai (2013)	Chang, Wu, and Hsu (2013), Dunleavy et al. (2009), Kamarainen et al. (2013) and Klopfer and Squire (2007)
Distributed cognition (Cole & Engeström, 1993)				Enyedy et al. (2015) and Tolentino et al. (2009)
Historical reasoning (van Drie & van Boxtel, 2008)				Harley et al. (2016)
Scaffolding participatory simulation for mobile learning				Yin et al. (2013)

The theory of knowledge integration, however, was taken into account in the studies of Quadrant II. A knowledge integration perspective was addressed to assist students develop scientific criteria to evaluate their existing ideas and new scientific ideas, as well as utilize them in novel situations (Linn & Eylon, 2011). Beyond increasing students' understanding of abstract and complex concepts, the studies of Quadrant II paid attention to the use of technology for transferrable learning and the integration of different knowledge. Nevertheless, the majority of the studies in Quadrant II seemed to lack a solid theoretical basis to well explain the unique affordances of AR use.

In Quadrant III and IV, however, a large number of AR applications with a context-aware design were based on learning theories, such as situated learning and distributed cognition. Both of these two theories emphasize learning through interaction with humans and tools in authentic activities where context is important, and are rooted in the sociocultural theory as proposed by Vygotsky. "Central to the situated learning theory perspective is the belief learning is embedded within, determined by, and inseparable from a particular physical and cultural setting." (Dunleavy, Dede, & Mitchell, 2009, p. 9). Knowing, doing, and context are intertwined and interdependent. The learning environment is essential to the process, because the context can alter, enhance, and support certain types of performances, approaches to problems, and learning activities (Squire & Jan, 2007).

The unit of analysis underlying the situated learning theory is usually the relationship between the individuals and the environment. From this perspective, learning and cognition are understood as the progress along trajectories of participation in AR-supported practices and as the ongoing transformation of identity. The theory of distributed cognition provides an apt description of a dynamic system with tools, artifacts, representations, and other humans. Hence, the unit of analysis underlying the theory of distributed cognition is a cognitive system. Grounded in the theory of distributed cognition, Enyedy et al. (2015) proposed the concept of Liminal Blends, as a distributed unit of analysis, which helps to trace how students stretch their understanding of a concept across their bodies, materials artifacts, and the contribution from the multiple students in AR learning environments.

4.3 Integrated Pedagogical Approaches or Strategies

It was further observed that, without clear theoretical foundations, there were few studies of Quadrant I and II that tried to integrate concrete pedagogical approaches or strategies with AR system or activity design. Game-based learning (or gamification) was most commonly used in the design of AR learning environments. In Quadrant I and II, a majority of them focused on the design of AR books, instructions, or labs. Initially, the studies categorized into these two quadrants emphasized the students' perceived usability of interaction. More recently, a growing number of studies began to pay attention to user learning experiences, such as perceiving enjoyment, usefulness, and entertainment (e.g., Giasiranis & Sofos, 2017; Ibáñez, Di Serio, Villarán, & Delgado Kloos, 2014).

Table 3 illustrates that a variety of pedagogical approaches or strategies had been taken in the design of context-aware AR learning, including game-based learning (Dunleavy et al., 2009; Hwang et al., 2016; Klopfer & Squire, 2007), collaborative problem-based learning (Tolentino et al., 2009; Liu, Tan, & Chu, 2009), inquiry-based learning (Bressler & Bodzin, 2013; Chiang, et al., 2014; Kamarainen et al., 2013), task-based collaborative learning (Liu, 2009), dramatic play (Han et al., 2015), etc. Meanwhile, the variation of these approaches and strategies could be found in the AR applications in different subjects.

Table 3 The pedagogical approaches or strategies used

	Context-independent		Context-aware	
	Quadrant I	Quadrant II	Quadrant III	Quadrant IV
Kindergarten				Dramatic play (Han et al., 2015)
K12_Math				
K12_Science	**Game-based learning** (Lu & Liu, 2015)		**Game-based learning** (Hwang et al., 2016)	**Digital storytelling** (Laine et al., 2016) **Inquiry-based learning** (Bressler & Bodzin, 2013; Chiang et al., 2014; Kamarainen et al., 2013) **Game-based learning** (Klopfer & Squire, 2007) **Collaborative problem-based learning** (Tolentino et al., 2009; Liu et al., 2009)
K12_Language learning and other social studies		**Game-based learning** (Tobar-Muñoz et al., 2017)		**Digital storytelling** (Sugimoto, 2011) **Inquiry-based learning** (Chang et al., 2013) **Game-based learning** (Dunleavy et al., 2009) **Task-based collaborative learning** (Liu, 2009)
University				**Historical reasoning through inquiry** (Harley et al., 2016) **Experiential learning** (Yin et al., 2013)
Training/workplace learning				**Peer assessment** (Chao et al., 2016)
Special education				

The integration of the pedagogical design with AR technique in science education was relatively mature, compared to the other fields. More recently, as disciplinary integration became more important, the pedagogical approaches of some subject areas are transferred and shared with those of other subjects. A typical case is about using inquiry-based learning in social science learning (e.g., Chang et al., 2013; Harley et al., 2016). In science education, the combination of mobile AR technology and pedagogical inquiry activities has been shown to be effective in promoting students' understanding of the science content (Chang et al., 2013). The findings of study of Harley et al. (2016) revealed that fostering historical reasoning through the integration of AR-based inquiry-supportive elements could improve learning. As they stated, AR helped immerse learners into the past (as well as the present) by blending real-life setting with virtual information that can enhance learning experiences. Their findings were in line with the study of Chang et al. (2015) about applying the AR in a mobile guidance system to increase the sense of place for heritage places. They pointed out that AR-enhanced location-based learning as AR-enabled students to observe and experience comparisons between the past and the present, and in this way helped to increase the level of immersion.

Another example is about adopting digital storytelling in science learning (Laine et al., 2016). When used in education, this pedagogical approach has been proven to improve twenty-first-century skills and multiple literacy skills (Robin, 2008). Sugimoto (2011) demonstrated a system that used a robot and a handheld projector for supporting students' storytelling activities, and the findings suggested that the mixed-reality environment could enhance students' embodied participation and creativity of storytelling. In science education, digital storytelling has been used in science learning games to spark intrinsic motivators and improve participants' problem-solving competence (Hung, Hwang, & Huang, 2012). Laine et al. (2016) combined storytelling, gaming, and AR to assist students in comprehending scientific topics and evidenced that AR could be a powerful motivator in the learning process.

5 Discussion

This study proposes a framework for organizing AR applications in education. Instead of distinguishing the location-based AR studies from the image-based AR studies, the concepts of deep learning and of context-aware design were used to distinguish the different AR applications in education. Findings from this review showed that those context-independent AR applications focused more on conveying content information in an alternative approach but paid less attention to the pedagogical design. The context-aware AR applications, however, underlying the learning theories, such as situated learning and distributed cognition, tended to have more holistic learning environment designs by integrating diverse pedagogical approaches and strategies. Moreover, the majority of the context-aware AR applications worked on taking use of AR to increase collaboration and knowledge transfer in the different scenarios, beyond multimodal or multimedia content presentations.

This review study suggests that further studies of AR applications in teaching and learning are needed to study context-aware learning designs. Two concrete suggestions are pinpointed and summarized. They are (1) foregrounding design of human—context interactions; and (2) designing immersive learning experience to achieve distributed cognition.

5.1 Foregrounding Design of Human–Context Interactions

It has been noted that AR not only provides each individual with a new interactive approach to realize human and computer interaction but also integrates human–computer–context interactions. Hence, in future AR studies, in addition to providing rich content via 3D models or environments, more attention should be paid to on exploring how to enhance the interactions between learners and the contextual information through pedagogical content design. In the design, the link between virtual information and authentic environments should be emphasized. As Klopfer and Squire (2007) pointed out in their early study, successful AR applications require learners to solve complex problems in which they have to use a combination of real collected evidence and virtual information. One mechanism for achieving this is to design context-aware applications on mobile devices. Meanwhile, the integration of pedagogical designs (such as collaborative problem-solving or task-based inquiry learning) with AR also can help increasing authentic learning contexts where participants need to solve problems or complete tasks together.

In terms of current technology developments, we can see that human–computer interactions are gradually moving closer to more natural forms of interaction (Shi, 2018). While speech, handwriting, and vision interfaces are relatively more well developed, new interfaces like touch and gestures are interaction tasks related, and more research advances in these areas have the potential to transform the human—context interfaces.

5.2 Designing Immersive Learning Experience to Achieve Distributed Cognition

Like the use of Virtual Reality (VR) in education, the use of AR in education enables the power of immersion which may provide a first-person form of experiential learning. Beyond cultivating interests, motivation, and engagement in learning, the first-person learning experience in a virtual environment has the advantage of developing learner autonomy which is particularly important to lifelong learning. One of the most significant affordances of AR is providing an immersive hybrid learning environment that combines virtual and physical objects. Nevertheless, the purpose of using AR in education is not to replicate or replace real-world interactions with highly immersive environments. As Lindgren and Johnson-Glenberg (2013) stated that AR environments may be particularly well aligned with collaborative activity, social interactions typically involve physical interplay between participants, and the structure of AR can facilitate and enhance these interactions. AR designers can focus on use of AR to enable learners to build up common ground for shared understanding.

6 Conclusion

The use of AR in education can be considered as one of the natural evolutions from traditional instructional design to constructivism, because it enables the power of immersion and embodied learning providing the first-person form of experiential learning, and it has the potential to recognize the context the learner is situated in. Our review indicates that the dimension of context-aware design can be a contributing factor toward whether the learning approach utilizing AR leads to surface-type learning or is intentional toward developing deep learning. Productive ways of using AR to promote deep learning need to be built on a foundation of strong learning theory such as to achieve distributed cognition. We hope to see more of such studies that can illuminate the real affordances of AR in education that taps on both digital and non-digital resources.

References

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review, 20,* 1–11.

Bacca, J., Baldiris, S., Fabregat, R., Graf, S., & Kinshuk. (2014). Augmented reality trends in education: A systematic review of research and applications. *Educational Technology & Society, 17*(4), 133–149.

Biggs, J. B. (1987). *Student approaches to learning and studying*. Hawthorn, Victoria: Australian Council for Educational Research.

Bressler, D. M., & Bodzin, A. M. (2013). A mixed methods assessment of students' flow experiences during a mobile augmented reality science game. *Journal of Computer Assisted learning, 29*(6), 505–517.

Cabero, J., & Barroso, J. (2016). The Educational possibilities of augmented reality. *New Approaches in Educational Research, 5*(1), 44–50.

Chang, Y. L., Hon, H. T., Pan, C. Y., Sung, Y. T., & Chang, K. E. (2015). Apply an augmented reality in a mobile guidance to increase sense of place for heritage places. *Educational Technology and Society, 18*(2), 166–178.

Chang, H. Y., Wu, H. K., & Hsu, Y. S. (2013). Integrating a mobile augmented reality activity to contextualize student learning of a socioscientific issue. *British Journal of Educational Technology, 44*(3), 95–100.

Chao, J., Chiu, J. L., DeJaegher, C. J., & Pan, E. A. (2016). Sensor-augmented virtual labs: using physical interactions with science simulations to promote understanding of gas behavior. *Journal of Science Education and Technology, 25*(1), 16–33.

Cheng, K.-H., & Tsai, C.-C. (2013). Affordances of augmented reality in science learning: suggestions for future research. *Journal of Science Education and Technology, 22*(4), 449–462.

Chiang, T. H. C., Yang, S. J. H., & Hwang, G. (2014). *An augmented reality-based mobile learning system to improve students' learning achievements and motivations in natural science inquiry activities.pdf* (Vol. 17, pp. 352–365).

Cole, M., & Engeström, Y. (1993). A cultural-historical approach to distributed cognition. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 47–87). New York: Cambridge University Press.

Dey, A. K. (2001). Understanding and using context. *Personal and Ubiquitous Computing, 5*(1), 4–7.

Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. *Journal of Science Education and Technology, 18*(1), 7–22.

Enyedy, N., Danish, J. A., & DeLiema, D. (2015). Constructing liminal blends in a collaborative augmented-reality learning environment. *International Journal of Computer-Supported Collaborative Learning, 10*(1), 7–34.

Floyd, K. S., Harrington, S. J., & Santiago, J. (2009). The effect of engagement and perceived course value on deep and surface learning strategies. *Informing Science: the International Journal of an Emerging Transdiscipline, 12,* 181–190.

Giasiranis, S., & Sofos, L. (2017). Flow experience and educational effectiveness of teaching informatics using AR. *Educational Technology and Society, 20*(4), 78–88.

Han, J., Jo, M., Hyun, E., & So, H. jeong. (2015). Examining young children's perception toward augmented reality-infused dramatic play. *Educational Technology Research and Development*, *63*(3), 455–474.

Harley, J. M., Poitras, E. G., Jarrell, A., Duffy, M. C., & Lajoie, S. P. (2016). Comparing virtual and location-based augmented reality mobile learning: emotions and learning outcomes. *Educational Technology Research and Development, 64*(3), 359–388.

Hmelo-silver, C. E., & Barrows, H. S. (2006). Goals and strategies of a problem-based learning facilitator. *Interdisciplinary Journal of Problem-Based Learning, 1*(1), 21–39.

Hung, Y. H., Chen, C. H., & Huang, S. W. (2017). Applying augmented reality to enhance learning: A study of different teaching materials. *Journal of Computer Assisted learning, 33*(3), 252–266.

Hung, C. M., Hwang, G. J., & Huang, I. (2012). A project-based digital storytelling approach for improving students' learning motivation, problem-solving competence and learning achievement. *Educational Technology & Society, 15*(4), 368–379.

Hwang, G. J., Wu, P. H., Chen, C. C., & Tu, N. T. (2016). Effects of an augmented reality-based educational game on students' learning achievements and attitudes in real-world observations. *Interactive Learning Environments, 24*(8), 1895–1906.

Ibáñez, M. B., Di Serio, Á., Villarán, D., & Delgado Kloos, C. (2014). Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness. *Computers & Education, 71,* 1–13.

Johnson, L., Adams, S., Cummins, M., Estrada, V. (2012). *Technology Outlook for STEM + Education 2012–2017. NMC Horizon Report Sector Analysis*. Austin, TX: The New Media Consortium.

Kamarainen, A. M., Metcalf, S., Grotzer, T., Browne, A., Mazzuca, D., Tutwiler, M. S., et al. (2013). EcoMOBILE: Integrating augmented reality and probeware with environmental education field trips. *Computers & Education, 68,* 545–556.

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

Laine, T. H. (2012). *Technology integration in context-aware learning spaces*. Joensuu: University of Eastern Finland.

Laine, T. H., Nygren, E., Dirin, A., & Suk, H. J. (2016). Science Spots AR: A platform for science learning games with augmented reality. *Educational Technology Research and Development, 64*(3), 507–531.

Lindgren, R., & Johnson-Glenberg, M. C. (2013). Emboldened by embodiment: Six precepts for research on embodied learning and mixed reality. *Educational Researcher, 42*(8), 445–452.

Linn, M. C., & Eylon, B. S. (2011). *Science learning and instruction: Taking advantage oftechnology to promote knowledge integration*. New York, NY: Routledge.

Liu, T. Y. (2009). A context-aware ubiquitous learning environment for language listening and speaking. *Journal of Computer Assisted learning, 25*(6), 515–527.

Liu, T. Y., Tan, T. H., & Chu, Y. L. (2009). Outdoor natural science learning with an RFID-supported immersive ubiquitous learning environment. *Educational Technology and Society, 12*(4), 161–175.

Lu, S. J., & Liu, Y. C. (2015). Integrating augmented reality technology to enhance children's learning in marine education. *Environmental Education Research, 21*(4), 525–541.

Marton, F., & Säljö, R. (1976). On qualitative differences in learning I: Outcome and process. *British Journal of Educational Psychology, 46,* 4–11.

Mayer, R. E. (2009). *Multimedia learning*. Cambridge, UK: Cambridge University Press.

Milgram, P. & Kishino, F. (1994). Augmented reality: A class of displays on the reality-virtuality continuum. In SPIE, pp. 282–292.

Montoya, M. H., Díaz, C. A., & Moreno, G. A. (2017). Evaluating the effect on user perception and performance of static and dynamic contents deployed in augmented reality based learning application. *Eurasia Journal of Mathematics, Science and Technology Education, 13*(2), 301–317.

Pejoska, J., Bauters, M., Purma, J., & Leinonen, T. (2016). Social augmented reality: Enhancing context-dependent communication and informal learning at work. *British Journal of Educational Technology, 47*(3), 474–483.

Pellegrino, J. W., & Hilton, M. L. (2012). *Education for Life and Work: Developing Transferable Knowledge and Skills in the 21st Century.* National Academy of Sciences.

Robin, B. R. (2008). Digital storytelling: A powerful technology tool for the 21st century classroom. *Theory Into Practice, 47*(3), 220–228.

Salinas, P., & Pulido, R. (2017). Understanding the conics through augmented reality. *Eurasia Journal of Mathematics, Science and Technology Education, 13*(2), 341–354.

Schilit, B., Adams, N., & Want, R. (1994). Context-aware computing applications. *In Proceedings of the Workshop on Mobile Computing Systems and Applications* (pp. 85–89), Santa Cruz, CA: IEEE Computer Society.

Shi, Y. (2018). Interpreting user input intention in natural human computer interaction. In *Proceedings of UMAP'18, July 8–11, 2018*, Singapore, pp. 277–278.

Squire, K. D., & Jan, M. (2007). Mad city mystery: Developing scientific argumentation skills with a place-based augmented reality game on handheld computers. *Journal of Science Education and Technology, 16*(1), 5–29.

Sugimoto, M. (2011). A mobile mixed-reality environment for children's storytelling using a handheld projector and a robot. *IEEE Transactions on Learning Technologies, 4*(3), 249–260.

Tobar-Muñoz, H., Baldiris, S., & Fabregat, R. (2017). Augmented reality game-based learning: enriching students' experience during reading comprehension activities. *Journal of Educational Computing Research, 55*(7), 901–936.

Tolentino, L., Birchfield, D., Megowan-Romanowicz, C., Johnson-Glenberg, M. C., Kelliher, A., & Martinez, C. (2009). Teaching and learning in the mixed-reality science classroom. *Journal of Science Education and Technology, 18*(6), 501–517.

van Drie, J., & van Boxtel, C. (2008). Historical reasoning: Towards a framework for analyzing students' reasoning about the past. *Educational Psychology Review, 20,* 87–110.

Wen, Y. (2018). Chinese character composition game with the augmented paper. *Educational Technology & Society, 21*(3), 132–145.

Wickens, C. D., Hollands, J. G., Banbury, S., & Parasuraman, R. (2016). *Engineering psychology & human performance*. Pearson, NJ: Psychology Press.

Wu, H. K., Lee, S. W. Y., Chang, H. Y., & Liang, J. C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education, 62,* 41–49.

Yin, C., Song, Y., Tabata, Y., Ogata, H., & Hwang, G.-J. (2013). Developing and implementing a framework of participatory simulation for mobile learning using scaffolding. *Educational Technology & Society, 16*(3), 137–150.

Yoon, S., Anderson, E., Lin, J., & Elinich, K. (2017). How augmented reality enables conceptual understanding of challenging science content. *Educational Technology and Society, 20*(1), 156–168.

Chapter 10
Virtual Reality Environments (VREs) for Training and Learning

Kalliopi-Evangelia Stavroulia, Maria Christofi, Telmo Zarraonandia, Despina Michael-Grigoriou and Andreas Lanitis

1 Introduction

The term Virtual Reality (VR) was first used by Jaron Lanier, founder of VPL Research, in 1989, when he began to develop goggles and gloves, which were needed to experience what he called VR. We live at a time where advances in the field of VR are moving rapidly. People in VR are immersed in an environment that is realized through computer-controlled display systems, and with the possibility to affect changes in that environment (Sanchez-Vives & Slater, 2005).

VR provides users the ability to experience realistic scenarios, environments and situations, and chances are they will likely react natural and realistically, so we could say that VR simulates reality. Examples of current uses of VR in real applications include simulations (Aristidou & Michael, 2014; Michael, Kleanthous, Savva, Christodoulou, Pampaka, & Gregoriades, 2014), training, learning (Christofi et al., 2018; Pappa, Ioannou, Christofi, & Lanitis, 2018) and phobias treatment (Christofi & Michael-Grigoriou, 2016).

K.-E. Stavroulia (✉) · M. Christofi
Cyprus University of Technology, Limassol, Cyprus
e-mail: kalliopi.stavroulia@cut.ac.cy

M. Christofi
e-mail: mu.christofi@edu.cut.ac.cy

T. Zarraonandia
Universidad Carlos III de Madrid, Madrid, Spain
e-mail: tzarraon@inf.uc3m.es

D. Michael-Grigoriou · A. Lanitis
Cyprus University of Technology & RISE Research Centre on Interactive Media, Smart Systems and Emerging Technologies, Limassol, Cyprus
e-mail: despina.grigoriou@cut.ac.cy

A. Lanitis
e-mail: andreas.lanitis@cut.ac.cy

P. Díaz et al. (eds.), *Learning in a Digital World*, Smart Computing and Intelligence, https://doi.org/10.1007/978-981-13-8265-9_10

In the broad area of training, immersive VR and its power of interaction with virtual objects and visualization (Norrby, Grebner, Eriksson, & Bostrom, 2015) could be extremely helpful. People can be trained in a virtual environment alone or in a shared environment with others. Virtual environments have many advantages over real ones; they can be used to experiment safely, and they are controllable. Any environment can be created, realistic or fictional, for the purposes of the training. When using VR technology for training, it is possible to repeat training exercises as many times as required without additional cost. Interaction could vary as well, depending on the cause and the specific field of training. VR has also the advantage of the three-dimensional representation of objects, which is really important for understanding and learning.

An area that VR training is being used is in sports and physical training in general. What makes VR ideal for this area is that when an HMD is combined with the body tracking of the user, or at least hand or foot tracking, it could be utilized to train athletes (Miles, Pop, Watt, Lawrence, & John, 2012) or normal people to play sports or even just for exercising without having the need to go to an actual gym. It can be also used to understand perception and action in sports (Craig, 2013) and even analysing sports performance (Bideau et al., 2010). VR has the potential to make exercise more fun for people. One example could be to connect an exercise bike to a display, so the user can view a landscape while biking, and the scenery would change accordingly to his actions. Similarly, it is possible to connect a treadmill to a VR display, so that the user could walk on the moon for example, or a forest or an imaginary setting. This is the power of VR, it allows us to go beyond our reality, and make people feel like they are exercising on another planet, or walk on another place rather than the gym, and this could motivate them to exercise more.

Often, experts coming from a variety of fields like doctors, lawyers or even psychologists are required to make decisions with multiple results for the recipients. VR environments can provide those experts an ideal space to replicate situations similar to those that they face, providing them the opportunity to be trained as many times as necessary and experiment on the proper course of action but within a safe three-dimensional environment. For instance, VREs could provide medical students a virtual setting like a hospital, for example, allowing them to interact with the human body or with virtual patients minimizing the risk of harming a real patience (Cendan & Lok, 2012; Cook, Erwin, & Triola, 2010; Kleinsmith, Rivera-Gutierrez, Finney, Cendan, & Lok, 2015; Michael-Grigoriou, Yiannakou, & Christofi, 2017).

A more specific area that VR has been used and researched thoroughly is training surgeons and medical students (Alaraj et al., 2011). VR simulations are being used for training, teaching and planning for surgeries. It is an area that the advantages of virtual environments are most visible, because it is easier and better to train on virtual bodies than real ones. These simulations have visual displays combined with haptic devices that are important for the user to apply forces to the virtual object and at the same time feel back the resistance from the object. Reviews and meta-analyses regarding the effectiveness of VR training simulations used in training have been conducted as well (Al-Kadi et al., 2012; Zendejas, Brydges, Hamstra, & Cook, 2013).

VR can be a powerful tool in the research of empathy for learning and education. VR technologies have been used for inducing empathy towards groups of people that are stigmatized by society (Christofi & Michael-Grigoriou, 2017). Empathy in this context was induced into student learning about international studies. Stover (2007) described a computer simulation that allowed students to participate in the emotional effect of the Cold War, developing a sense of empathy with decision-makers and having a better appreciation about the risk, danger and fear associated with the Cold War.

2 Literature Review

2.1 Introduction

The last few years, the use of Virtual Reality Environments (VREs) in the field of education has attracted the interest of the scientific community that seeks new ways to bring technology into the learning process. The use of VR as a teaching and learning instrument demands taking into consideration several pedagogical principles to guide the implementation of activities. From an educational perspective, VR approaches can be used to support constructivist learning theory, offering users engaging learning activities allowing them to conquer knowledge on their own and connect it to their previous knowledge (Aiello, D'Elia, Di Tore, & Sibilio, 2012; Eschenbrenner, Nah, & Siau, 2008).

2.2 The Significance of Virtual Reality in the Learning Process

Research revealed numerous benefits of using VR-based approach in the field of education. Most importantly, VR technology allows the development of virtual worlds that mimic the real world, simulating real-based incidents and situations, providing the users a space that suits their needs for training and learning through experimentation (Eschenbrenner et al., 2008). Thus, within VREs, users are able to experience authentic and realistic scenarios and situations closely connected to real life, within which they can behave and respond as they would do in the real world (Parsons, Bowerly, Buckwalter, & Rizzo, 2007). Moreover, the VR situations are easily controllable making VREs a valuable training tool (Rizzo et al., 2009). Another significant issue is that learners could potentially feel more psychologically present in virtual environments compared to the traditional learning methods (Bailenson et al., 2008). That fact makes VREs an extremely useful therapeutic tool for the treatment of anxiety disorders (Powers & Emmelkamp, 2008), social phobia (Klinger et al., 2005), public speaking anxiety (Harris, Kemmerling, & North, 2002), fear of spiders (Garcia-Palacios, Hoffman, Carlin, Furness Iii, & Botella, 2002) or even fear of flying (Rothbaum, Hodges, Smith, Lee, & Price, 2000).

Apart from the fact that VR allows the design of virtual spaces that are identical to the real ones, more importantly within those environments the performance of the user can be measured and be used for multiple purposes including training (Rizzo et al., 2009). Of great value is also the fact that not only the knowledge gained within the VRE can be transferred to the real world but also the knowledge from the real world can be used within the VR environment (Eschenbrenner et al., 2008; Huang, Backman, Chang, Backman, & McGuire, 2013; Parsons et al., 2007). As an illustration, VREs have been used for job interview training in order to enhance interview skills and self-confidence for individuals, so as to have greater odds of receiving a job and weed out their anxiety (Smith et al., 2015). Equally important is the fact that VREs allow the users to experience a scenario from multiple different perspectives, understanding the different aspects of a situation (Bailenson et al., 2008). Therefore, the users can experiment in a risk-free environment and learn by trial and error (Freina & Ott, 2015; Rizzo et al., 2009). For example, in the past, we could read a book and try to enter the position of the character, but within a VRE it is possible for genders to swap bodies, so a woman could feel as being inside of the body of a man and vice versa (Bertrand, Gonzalez-Franco, Cherene, Pointeau, 2014; Kuchera, 2014; Rutherford-Morrison, 2015).

Another significant issue is that VREs allow training in situations where it is impossible to do it in a physical space due to the cost or possible danger (Bailenson et al., 2008; Freina & Ott, 2015). However, within a simulated virtual environment that represents real-life dangerous situations, learners can experience crises situations but within a safe environment with room for error and no danger (Bailenson et al., 2008; Freina & Ott, 2015). For this reason, VR is often used in vocational training providing practical experiences to workers of areas in which real-life training is not an option due to lack of access or because the danger is very high (Freina & Ott, 2015). To illustrate, it is not possible to train in real scenarios firefighters or bioterrorist response units as those dangerous situations cannot be created in reality. However, within VREs that represent real-life dangerous crisis, the users can experience such chaotic and stressful crisis and through continuous training be prepared to act accordingly if needed (Bailenson et al., 2008). For instance, VR can be used as an educational tool to train young people face and survive against natural disasters such as fire and earthquakes. Using VR technology allows the users to step inside the disaster and thus, experience a remarkably realistic experience while they are trained to avoid dangerous actions like going near windows or touching flames aiming to reduce their fear during the disaster (Dumol, Lascano, Magno, & Tiongson, 2014).

Another important aspect is that VREs can support knowledge acquisition by supporting different learning styles such as visual, auditory or kinesthetic (Lee & Wong, 2014; Freina & Ott, 2015). In this way, the virtual worlds match the needs of the trainees leading to knowledge mastering (Rizzo et al., 2009). Apart from visual capabilities, VR can offer the users haptic and auditory capabilities, maximizing their experience in the virtual world and more importantly their learning. Those capabilities provide a multisensory immersive journey maximizing the user experience and level of realism of the VRE supporting in that way highly demanding training activities such as training for medical doctors (Bailenson et al., 2008).

VR allows the visualization of the educational content, allowing the users to better understand concepts that are difficult to present dynamically in the traditional classroom (Eschenbrenner et al., 2008). Hence, the users gain deeper understanding and sense of caring for the topic leading to increased enthusiasm for learning (Freina & Ott, 2015). Moreover, the users are offered instant feedback allowing reflection and maximization of learning and performance (McComas, Pivik, & Laflamme, 1998). The fact that VR can increase learner's involvement, motivation and engagement of the users in the simulated activities (Freina & Ott, 2015; Huang et al., 2013) can support supplementary to traditional teaching methods allowing teachers to spend the classroom time in more effective activities for the students such as discussions and group work (Eschenbrenner et al., 2008). Furthermore, instructors can develop cooperative activities with VREs promoting communication, collaboration and social skills of the users (Bailenson et al., 2008; Eschenbrenner et al., 2008; McComas et al., 1998). Using VREs is an innovative approach that can promote creativity skills allowing users to develop their own VRE, which results in idea generation, while offering new educational opportunities (Eschenbrenner et al., 2008).

Research regarding the use of VR in education sector is still at its infancy and there is limited yet growing body of research indicating the potential of using such an approach. Freina and Ott (2015) conducted a literature research related to the use of virtual reality in education and the results revealed that most of the papers are related to the subjects of computer science, engineering, social sciences and medicine. Moreover, most virtual reality research papers have to do with university or pre-university while VR appears to be used in adult training in areas in which practice in the real setting is impossible due to lack of access or danger. Despite the limited body of research, the results indicate significant positive effects on teaching and learning in many different thematic areas. For example, VR environments have been used for pedestrian safety training (Schwebel, Combs, Rodriguez, Severson, & Sisiopiku, 2016); children with attention-deficit/hyperactivity disorder (ADHD) (Rizzo et al., 2009), children with disabilities (McComas et al., 1998) and children with Autism Spectrum Disorder (ASD) (Parsons et al., 2007).

2.3 Limitations of VR

Despite the several positive aspects of using VR in education, there are several limitations and challenges that need to be addressed. One of the more significant challenges is to ensure that the designed activities of VR applications developed for educational purposes meet the pedagogical objectives that must be achieved, providing the necessary educational added value to learners (Eschenbrenner et al., 2008). VREs have the potential to enhance teaching and learning; however, it is essential to establish the theoretical framework that will guide the design and development of the VR system aiming to promote effective learning (Chen, 2006).

Technological problems must be taken into consideration as the continuous technological advancements have not yet eliminated all the technical difficulties, while the design of the VREs is also a complex issue (Huang & Alessi, 1998). Another important limitation is that the acquisition of high-fidelity VR technology by many educational institutions such as schools is difficult due to the cost in combination with the lack of resources devoted to education. As a result, in many cases where perishable groups such as students with severe disabilities will require such an equipment the cost for the families will be unreachable (Eschenbrenner et al., 2008; McComas et al., 1998). Health and safety issues in the form of dizziness and risk of accidents associated with the use of the VR equipment cannot be neglected; hence, safety measures need to be taken into serious consideration when using VR for education (Eschenbrenner et al., 2008).

Additionally, the lack of experience in the use of such technology by teachers and students can cause problems (Eschenbrenner et al., 2008). Thus, training for familiarization to this technology is essential so as for the learning purposes not to be downgraded, which is time-consuming (Pantelidis, 2010). Additionally, due to this unfamiliarity with this technology, developing VR applications by teachers to meet the needs of the students is difficult, and thus teachers need to rely on already existing material that not only is extremely limited but probably does not meet their needs. Ideally, teachers should have at their disposals tools that would allow them to create VR applications customized to their teaching needs. Furthermore, there is a lack of research related to primary and secondary education; however, several factors must be taken into consideration including the demands of conducting research in a school setting and the recommendations related to the use of the 3D glasses by children (Freina & Ott, 2015).

It is also worth mentioning that there are several researchers related to the use of VR in education including the use of three-dimensional environments. However, most of those researches refer to the use of second life and similar virtual worlds consider 3D computer visualization as VR, yet they do not include the use of special electronic equipment, such as HMD glasses, that support the immersion of users.

2.4 Opportunities: VR Capabilities, Immersion, Presence and Embodiment

2.4.1 VR Technical Capabilities

The typical VR system we would recognize until a few years ago focused around vision and sound. The latest developments in VR are experimenting with the use of specialized suits and gloves to provide the users with tactile and force feedback as well. Most rarely smell and taste are included in a VR system.

The goal is to substitute the users' real sensory data with the virtual ones so that to immerse users into a virtual world and make them believe that they have a highly realistic experience. More technically, VRs' goal is to replace the users' real sense perceptions with the virtual ones. Many researchers in the 90s have found some of the factors that are fundamental to achieve this sensory substitution (Heeter, 1992; Held & Durlach, 1992; Slater & Wilbur, 1997; Steuer, 1992) which include head tracking, high-resolution displays, wide field-of-view vision, stereo and low latency. Nowadays, new factors arose including body tracking. VR systems like the Oculus Rift and especially the newest Vive Pro (Vive, 2018) include dual-OLED displays with an industry leading resolution of 2880 × 1600 pixels, up to 10 × 10 m room-scale tracking, Hi-Res headphones, 3D spatial in integration and environmental noise cancellation and controllers for the interaction of the user inside of the virtual world.

2.4.2 Immersion, Presence and Embodiment

Three important concepts in the field of VR are immersion, presence and embodiment. A VR system that is considered as immersive is the one that can deliver the ability to perceive through natural sensorimotor contingencies. How immersive a VR system is is determined by the technology (Slater & Sanchez-Vives, 2016). Comparisons can also be done, and classifications of systems as being more immersive from one another. We could say that one VR system is "more immersive" than another one when it can simulate a perception the other system cannot. For example, a VR system containing an HMD with head tracking and real-time body tracking of the user could be considered "more immersive" than a Cave, because when using an HMD, you view a virtual body in the same place with your real one. You cannot accomplish this using a Cave.

A subjective correlate of immersion is the concept of presence. If a participant in VR perceives using his body in a natural way, then the simplest inference for her brain's perceptual system to make is that what is being perceived is the participant's actual surroundings. Presence then is the subjective illusion of "being there" in the environment you are viewing through the VR displays (Slater & Sanchez-Vives, 2016). Slater in 2009, deconstructed the concept of presence into two independent concepts: (i) Place Illusion (PI) and (ii) Plausibility Illusion (Psi). He refers to PI as the original idea of the illusion of being in the virtual place and to Psi as the illusion that the events experienced in VR are really happening (even though the participant knows that they are not). He mentions that Psi requires that the virtual environment responds to actions of the participant and when both PI and Psi exist then the participants will more likely behave realistically in VR. This fundamental aspect of VR to deliver experience that gives rise to illusory sense of place and an illusory sense of reality is what distinguishes it fundamentally from all other types of media.

If we require for the user to have a virtual representation in the virtual world, we would replace his real body with a virtual one. This process is called embodiment. Spanlang et al. (2014) described a technical setup to achieve embodiment. A typical setup would require an HMD with a wide field-of-view, head and body tracking in real time using devices like the Kinect or a motion capture suit or sensors.

3 VR for Training Teachers

Traditional teacher preparation programmes focus primarily on pedagogical issues and only in some cases include in-field practical experiences (Andreasen & Haciomeroglu, 2009; Dieker, Hynes, Hughes, & Smith, 2008; Katsarou & Dedouli, 2008; Ting, 2013). This results in the question of whether there should be an alternative training method that could provide teachers the in-field training that they need. Teaching practice in schools with real students is becoming more difficult to accomplish nowadays. Nonetheless, beginning teachers are expected to be of highly professional quality and practice.

Technology might give the answer to the request for a strong training tool in teacher preparation, enabling pre-service but also in-service teachers to improve the quality of their teaching performance. VR environments can be used for the development of highly effective and professional future teachers that will be successful in the classroom. Moreover, constant training within a virtual school environment will better prepare teachers and ensure their survival in today's digital and multicultural classrooms. The significance of using immersive VR environments in teacher training lies on the fact that the scenarios can simulate real-life-based phenomena and situations, while the knowledge gained within the VE can be transferred to the real world (Eschenbrenner et al., 2008; Huang et al., 2013; Parsons, 2016). Another key point is that VEs provide teachers a safe environment within which they can make mistakes but without influencing learning of real students and they can repeat the experience to work on their mistakes and no matter how many times teachers may want to experiment, the virtual students have no memory of the process (Dieker et al., 2008; Freina & Ott, 2015). By the same token, virtual classroom environments aim to provide an innovative training tool that can be used for constant professional development and update of teachers' skills so that teachers can remain productive (Dieker et al., 2008). Furthermore, the use of virtual environments will allow teachers to take control of their own learning, monitor their progress and thus learn more. Equally important is that the virtual environment will provide immediate feedback and data that in an actual classroom would be difficulty to identify (Dieker et al., 2008).

Despite the extensive use of VR in fields such as medicine and military, in the field of teacher education, its use is extremely limited. In the last few years, some attempts have been made in the preparation of teachers via virtual training environments. However, it should be noted that many of those attempts do not include the use of the VR equipment such as HMD glasses but provide the user a virtual classroom for experimentation through large screen displays. For instance, a prototype virtual environment named STAR Simulator was developed aiming to identify, recruit and train the best teachers by providing them rich experiences through interactions with the virtual students (Dieker et al., 2008). The results of the research revealed that it is possible to develop a virtual environment that can provide teachers with realistic and compelling experiences as if they were in a real classroom with real students (Dieker et al., 2008). Another mixed-reality environment called TeachMe was developed to train beginning teachers (Andreasen & Haciomeroglu, 2009). The prototype focused on behaviour and classroom management aspects and was to train beginning teachers before entering the classroom for the first time. The results of the research indicated the potential in training teachers via a simulated classroom environment helping them gain in-depth knowledge of their domain and assist the development of behaviour management strategies.

Using VR in teacher preparation and training is still at its infancy given the fact that this technology has still several limitations and high cost. Nevertheless, the first attempts seem promising and indicate the usability of such a tool in the field of teacher education. As part of our ongoing work in this field, several experiments with different scenarios took place aiming to give an innovative VR-based approach to teacher education and the related training methodology (Manouchou et al., 2016; Stavroulia et al., 2016, 2018a). For all the experiments HMD (Oculus Rift and VIVE) were used, in an effort to create an immersive experience to the users. Moreover, the design of the VR prototype followed a five-phase model—Analysis, Design, Development, Implementation and Evaluation—based on ADDIE model (Stavroulia et al., 2018a). Furthermore, to simulate real-life situations within the VR environment, apart from an extensive literature review research, data regarding teacher's real training needs were collected through survey and interviews with education experts (Stavroulia et al., 2018b). Examples of related work include the following: Experiencing Vision Disorders of Students: The objective was to raise teacher's awareness and maximize their skills in identifying similar vision problems by placing them to the position of a visually impaired student (Manouchou et al., 2016) (see Fig. 1). The results identified the potential of training teachers in student's vision disorders, while it is highly important the fact that many of the participants after the end of the experiment stated that they might have confused possible student's vision problems when looking at the blackboard that they were unaware of with indifference during the lesson.

Identifying Bullying: The aim of this experiment was to help teachers identify bullying issues and distinguish them from simple teasing between the students (Stavroulia et al., 2016). The results indicated that in-service teachers who participated felt extremely comfortable regarding their skills to identify bullying due to their experience and prof posed the use of VR only for pre-service teachers, yet what is interesting is the fact that they failed to distinguish bullying from simple teasing incident.

Dealing with multiculturalism and verbal bullying: This experiment had to do with multiculturalism and verbal bullying, to help teachers deal with today's multicul-

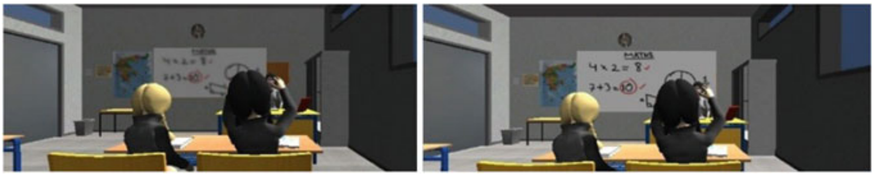


Fig. 1 The virtual environment showing blur (left) and clear (right) vision

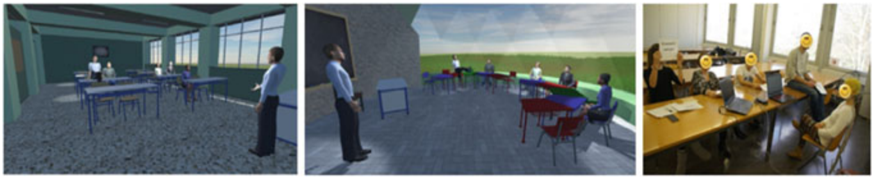


Fig. 2 The three different environments: Real-life based VRE (left), imaginary VRE (middle), real classroom setting (right)

tural classrooms and cultivate their empathy and reflection skills (Baka, Stavroulia, Magnenat-Thalmann, & Lanitis, 2018; Stavroulia & Lanitis, 2018; Stavroulia et al., 2018b). Another aim of the experiment was to investigate whether the participants would prefer training within a VR or in a physical classroom space (see Fig. 2). In this scenario, the participants were able to experience two different perspectives that allowed them to enter the position of a foreign student and experience verbal bullying by the classmates, while they were also able to see the incident through the eyes of the teacher. The results indicated that participants preferred training with the use of VR technology. Moreover, there were strong indications that training using VR helped the participants cultivate their empathy and reflection skills, while the experience provoked to them many emotions and mood states. Equally important is the fact that there are strong indications that the VR experience helped the participants to change the way they will attend to the needs of foreign students and the way they will react on disruptive behaviour among the students. Finally, it should be noted that there were participants coming from a different country who admitted that the scenario they experienced within the virtual world reminded them of a similar situation they experienced when they moved from their country to another for work obligations.

Drugs in School Environment: This application (see Fig. 3) relates to the problem of drug use in schools, a real and common problem that is underestimated and not properly addressed within the school setting, partially due to teachers' lack of training regarding how to address this issue (Stavroulia et al., 2018a). The scenario provided the users the ability to experience the problem from three different perspectives: through the eyes of the teacher, a healthy student and a student under drug use, to cultivate empathy. The results indicated differences after the use of the VR environment regarding empathy towards students facing drug-related disorders, while the scenario affected their emotions and mood states as there were significant differences after the experiment.

Overall, the first experiments indicate that VR can be a potential alternative paradigm for teacher education, offering teachers the possibility to be trained in real-life scenarios and situations. Additionally, with VR, it is possible to provide teachers the opportunity to live the life of someone else getting an idea of what someone else's life might be like. Hence, VR technology can allow teachers to live their students' life and experience different viewpoints, helping them to understand their students and their problems. Thus, VR can enhance significantly teacher's skills including empathy or reflection allowing them to establish strong communication channels with their students. Undoubtedly, further research is required regarding the use of VR in teacher training and there are many questions yet to be answered; however, it seems that it is only a matter of time for VR to become a new paradigm in teacher education and in the field of education in general.

4 VR for Training Students: Toolkit

In order to realize the many benefits that VR technology might report for education, it is necessary to facilitate the process of designing and developing VR environments. Due to the variety of skills and specialist knowledge required in their design and development, the production of this type of artefacts is still a challenging task, which usually entails high costs. In addition, it is necessary to consider the difficulty to guarantee on beforehand the effectiveness of the educational artefact produced. Investing in developing one VR environment without having the possibility to quickly modify it, adapt it or to develop more might result too expensive (Klopfer & Squire, 2008). Moreover, it will be necessary to put the design and development of these artefacts into the hands of those that experience problems that could be improved with it, that is, the end users (Von Hippel, 2005). In our case, these are the teachers and instructors, who have the knowledge and expertise required to create valuable educational experiences. For this to be done, it is necessary to provide this type of users–designers with adequate tools that take into account the specific requirements derived from their profile and do not impose an excessive cognitive workload. At that moment, most VR applications are created ad hoc, and there is little chance to reuse and adapt them without having a specialized technical background (Shih & Yang, 2008; Virvou & Katsionis, 2008).

During the last few years, the DEI Interactive System Group of the University Carlos III of Madrid has investigated the use of End User Development (EUD) techniques to empower educators to create educational technology. EUD is defined as "a set of methods, techniques and tools that allow users of software systems, who are acting as non-professional software developers, at some point to create, modify, or extend a software artefact" (Lieberman, Paternò, Klann, & Wulf, 2006). In this section, we present a EUD tool called VR-GREP (Virtual Reality Game Rules scEnario Platform) (Zarraonandia, Díaz, Montero, & Aedo, 2016), which aims to empower educators to create a specific type of VR educational artefact, VR seri-

Fig. 3 The three different perspectives: teacher (left), student drug user (middle), health student (right)

ous games, without requiring technical assistance. VR serious games will give the opportunity of combining many benefits that videogames can report in the context of education, as increasing the learner's motivation (Druckman, 1995) or self-regulated learning (Kim, Park, & Baek, 2009), with the opportunity that VR technology offers to live a realistic experience in the first-person perspective.

To empower educators to create VR serious games, without requiring technical assistance in the process, the VR-GREP uses two techniques: an immersive design of the game level and a definition of game rules as combinations of simpler games.

Immersive-level design. An essential part of designing a video game is the composition of the virtual scenario in which the play takes places. The scenario contributes to set the mood of the game, and its definition includes the specification of the game elements the player can interact with, as well as the background non-interactive elements, lighting, music and other ambient effects. In the case of a VR video game, the scenario of the game is a 3D virtual environment. Tools like Unity, Unreal or Blender allow to model this type of environments using a GUI and different views of the 3D virtual space. Although these tools are adequate for users with expertise in 3D modelling, having to control and modify the camera's viewpoint and viewing direction of the scene can be difficult for non-expert users. To avoid these issues, the VR-GREP platform supports modelling the virtual world immersively, from within the environment itself. This way the designer acts upon the player's experience of the environment, and not over a 2D representation of it. The designer navigates and interacts with the virtual scenario in a similar way as the player, testing the user's view even from an early stage of the design process. Moreover, this approach allows to carry out the modelling tasks using natural interaction techniques. The designer selects, places and modifies the objects in the scenario using her own hands. This saves from having to master new commands usually required to control and change between the different views and perspectives of the modelling tools.

Combinatorial rules design. To simplify the definition of the games rules, the VR-GREP tool implements the combinatorial approach described in (Zarraonandia, Diaz, & Aedo, 2017). This way, the rules of the game are described by selecting and combining the rules of simple archetypical games, such as treasure hunts, adventures or races. The designer links the elements in the virtual scenario with behaviours taken from those games, such as treasures to collect, enemies to avoid or goals to reach. As these behaviours and rules are well known, the designer is not required to learn a new design language for describing the game.

The VR-GREP Platform provides two applications: the edition tool and the runtime environment. The edition tool allows to create game designs following the approach described previously. The tool provides access to the Assets Repository, which contains graphical resources to model the virtual scenario of the game. The designs produced can be exported as XML files and stored in the platform's Games Repository. The runtime environment allows to select and retrieve game designs from the repository. It processes the game designs and automatically generates a virtual environment for the game by instantiating the assets specified in it.

Fig. 4 Screenshot of the VR-GREP editor: Entities menu (left) and rules menu (right)

The process of creating a game using the edition tool is as follows: First, the designer selects an initial setting, or background, for the game scene. The Assets Repository provides several predefined backgrounds that might range from simple empty terrains to more elaborated representations of environments, as rooms or forests, which already include trees, bushes, etc. Once the background of the scene has been selected, the author puts the HMD and starts exploring and transforming the virtual scene. This process is supported by the entities and edition menus (Fig. 4, left). The entities menu allows to select assets (entities) from the Assets Repository and add them to the scene. The edition menu allows to edit an entity in the scene to adjust its size, position and orientation. It is also possible to add entry points to other scenes so that more complex VR game scenarios can be created.

Once the game scenes have been defined, the next step is to specify the rules of the game. This process is supported by the rules menu (Fig. 4, right). Using this menu, the designer can select behaviours from archetypical games and link them to the entities in the scene. For example, the author can select the behaviour tool from the archetypical game adventure. This behaviour specifies that certain entity is a tool that when combined with some other specific entity, transforms the latter into something else. For example, a key can be set to be a tool for a closed door and to transform it into an open door.

Currently, the tool allows to link entities to behaviours taken from four archetypical games: treasure hunts, avoid enemies, race and adventures. These simple behaviours can be used to design games with an educational purpose. For example, the behaviour treasure to collect can be used in games in which the player has to identify elements or objects that satisfy certain condition. In a similar way, it could be used in a game for teaching basic biology to kids, in which the player has to identify the animals that are mammals. As another example, the behaviour tool from the adventure game can be used in games in which the player needs to establish relationships between objects or to learn the steps to follow to complete a procedure.

5 Conclusion

In this paper, we summarized some of the opportunities and challenges that the integration of VR in educational faces. We also presented two works that exemplify the vast possibilities of application of this technology. The potential of VR technology has just started to be explored, and more research needs to be done in order to understand how to exploit the benefits of VR in education. Educators need to be informed on the contexts and applications in which immersive learning experiences will improve the outcomes of traditional practices. Also, it is not only necessary to reduce the cost of the technology, but the design and development of the activity and educational content need to be facilitated. It is necessary to provide the teachers with the means to create VR application customized to their teaching needs.

Acknowledgements Authors acknowledge funding from the European Union's Horizon 2020 Framework Programme through NOTRE Project (H2020-TWINN-2015, Grant Agreement Number: 692058). Partially, this work is part of a project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°739578 and the government of the Republic of Cyprus through the Directorate General for European Programmes, Coordination and Development.

References

Aiello, P., D'Elia, F., Di Tore, S., & Sibilio, M. (2012). A constructivist approach to virtual reality for experiential learning. *E-Learning and Digital Media, 9*(3), 317–324.

Al-Kadi, A. S., Donnon, T., Paolucci, E. O., Mitchell, P., Debru, E., & Church, N. (2012). The effect of simulation in improving students' performance in laparoscopic surgery: A meta-analysis. *Surgical Endoscopy, 26*(11), 3215–3224.

Alaraj, A., Lemole, M. G., Finkle, J. H., Yudkowsky, R., Wallace, A., Luciano, C., … Charbel, F. T. (2011). Virtual reality training in neurosurgery: Review of current status and future applications. *Surgical Neurology International*, *2*.

Andreasen, J. B., & Haciomeroglu, E. S. (2009). Teacher training in virtual environments. In *Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*, Atlanta, GA.

Aristidou, K., & Michael, D. (2014). Towards building a diving simulator for organizing dives in real conditions. In *Proceedings of the 22nd International Conference in Central Europe on Computer Graphics, Visualization and Computer Vision 2014*. Plzen, Czech Republic.

Bailenson, J. N., Yee, N., Blascovich, J., Beall, A. C., Lundblad, N., & Jin, M. (2008). The use of immersive virtual reality in the learning sciences: Digital transformations of teachers, students, and social context. *The Journal of the Learning Sciences, 17*(1), 102–141.

Baka, E., Stavroulia, K. E., Magnenat-Thalmann, N., & Lanitis, A. (2018, June). An EEG-based evaluation for comparing the sense of presence between virtual and physical environments. In *Proceedings of Computer Graphics International 2018* (pp. 107–116). ACM.

Bertrand, P., Gonzalez-Franco, D., Cherene, C., & Pointeau, A. (2014). The machine to be another: Embodiment performance to promote empathy among individuals. Retrieved from http://www.themachinetobeanother.org/wp-content/uploads/2013/09/THE_MACHINE_TO_BE_ANOTHER_PAPER_2014.pdf.

Bideau, B., Kulpa, R., Vignais, N., Brault, S., Multon, F., & Craig, C. (2010). Using virtual reality to analyze sports performance. *IEEE Computer Graphics and Applications, 30*(2), 14–21.

Cendan, J., & Lok, B. (2012). The use of virtual patients in medical school curricula. *Advances in Physiology Education, 36*(1), 48–53.

Chen, C. J. (2006). The design, development and evaluation of a virtual reality based learning environment. *Australasian Journal of Educational Technology*, *22*(1).

Christofi, M., & Michael-Grigoriou, D. (2016). Virtual environments design assessment for the treatment of claustrophobia. In *2016 22nd International Conference on Virtual System & Multimedia (VSMM)* (pp. 1–8). IEEE.

Christofi, M., & Michael-Grigoriou, D. (2017). Virtual reality for inducing empathy and reducing prejudice towards stigmatized groups: A survey. In *2017 23rd International Conference on Virtual System & Multimedia (VSMM)* (pp. 1–8). IEEE.

Christofi, M., Kyrlitsias, C., Michael-Grigoriou, D., Anastasiadou, Z., Michaelidou, M., … & Pieri, K. (2018). A tour in the archaeological site of choirokoitia using virtual reality: A learning performance and interest generation assessment. In *Advances in digital cultural heritage* (pp. 208–217). Cham: Springer.

Cook, D. A., Erwin, P. J., & Triola, M. M. (2010). Computerized virtual patients in health professions education: A systematic review and meta-analysis. *Academic Medicine, 85*(10), 1589–1602.

Craig, C. (2013). Understanding perception and action in sport: How can virtual reality technology help? *Sports Technology, 6*(4), 161–169.

Dieker, L., Hynes, M., Hughes, C., & Smith, E. (2008). Implications of mixed reality and simulation technologies on special education and teacher preparation. *Focus on Exceptional Children, 40*(6), 1.

Druckman, D. (1995). The educational effectiveness of interactive games. In *Simulation and gaming across disciplines and cultures: ISAGA at a watershed* (pp. 178–187).

Dumol, T., Lascano, P., Magno, J., & Tiongson, R. (2014). Minmin escapes from disaster: An Oculus Rift disaster simulation game. *Philippine IT Journal, 7*(1), 49–54.

Eschenbrenner, B., Nah, F. F. H., & Siau, K. (2008). 3-D virtual worlds in education: Applications, benefits, issues, and opportunities. *Journal of Database Management (JDM), 19*(4), 91–110.

Freina, L., & Ott, M. (2015). A literature review on immersive virtual reality in education: State of the art and perspectives. *eLearning & Software for Education*, *1*(1).

Garcia-Palacios, A., Hoffman, H., Carlin, A., Furness Iii, T. A., & Botella, C. (2002). Virtual reality in the treatment of spider phobia: A controlled study. *Behaviour Research and Therapy, 40*(9), 983–993.

Harris, S. R., Kemmerling, R. L., & North, M. M. (2002). Brief virtual reality therapy for public speaking anxiety. *Cyberpsychology & Behavior, 5*(6), 543–550.

Heeter, C. (1992). Being there: The subjective experience of presence. P*resence: Teleoperators & Virtual Environments*, *1*(2), 262–271.

Held, R. M., & Durlach, N. I. (1992). Telepresence. *Presence: Teleoperators & Virtual Environments, 1*(1), 109–112.

Huang, M. P., & Alessi, N. E. (1998). Current limitations into the application of virtual reality to mental health research. In *Studies in health technology and informatics* (pp. 63–66).

Huang, Y. C., Backman, S. J., Chang, L. L., Backman, K. F., & McGuire, F. A. (2013). Experiencing student learning and tourism training in a 3D virtual world: An exploratory study. *Journal of Hospitality, Leisure, Sport & Tourism Education, 13,* 190–201.

Katsarou, E., & Dedouli, M. (2008). *Training and evaluation in education (in Greek).* Athens: PI-Pedagogical Institute of Greece.

Kim, B., Park, H., & Baek, Y. (2009). Not just fun, but serious strategies: Using meta-cognitive strategies in game-based learning. *Computers & Education, 52*(4), 800–810.

Kleinsmith, A., Rivera-Gutierrez, D., Finney, G., Cendan, J., & Lok, B. (2015). Understanding empathy training with virtual patients. *Computers in Human Behavior, 52,* 151–158.

Klinger, E., Bouchard, S., Légeron, P., Roy, S., Lauer, F., Chemin, I., et al. (2005). Virtual reality therapy versus cognitive behavior therapy for social phobia: A preliminary controlled study. *Cyberpsychology & Behavior, 8*(1), 76–88.

Klopfer, E., & Squire, K. (2008). Environmental detectives—The development of an augmented reality platform for environmental simulations. *Educational Technology Research and Development, 56*(2), 203–228.

Kuchera, B. (2014). Being someone else: How virtual reality is allowing men and women to swap bodies. Retrieved from http://www.polygon.com/2014/3/4/5423330/oculus-rift-vr-gender-swap-girl-mirror-look.

Lee, E. A. L., & Wong, K. W. (2014). Learning with desktop virtual reality: Low spatial ability learners are more positively affected. *Computers & Education, 79,* 49–58.

Lieberman, H., Paternò, F., Klann, M., & Wulf, V. (2006). End-user development: An emerging paradigm. In *End user development* (pp. 1–8). Dordrecht: Springer.

Manouchou, E., Stavroulia, K. E., Ruiz-Harisiou, A., Georgiou, K., Sella, F., & Lanitis, A. (2016). A feasibility study on using virtual reality for understanding deficiencies of high school students. In *2016 18th Mediterranean Electrotechnical Conference (MELECON)* (pp. 1–6). IEEE.

McComas, J., Pivik, P., & Laflamme, M. (1998). Current uses of virtual reality for children with disabilities. In *Studies in health technology and informatics* (pp. 161–169).

Michael-Grigoriou, D., Yiannakou, P., & Christofi, M. (2017). Intuitive interaction for exploring human anatomy in a VR setup. In *2017 23rd International Conference on Virtual System & Multimedia (VSMM)* (pp. 1–4). IEEE.

Michael, D., Kleanthous, M., Savva, M., Christodoulou, S., Pampaka, M., & Gregoriades, A. (2014). Impact of immersion and realism in driving simulator studies. *International Journal of Interdisciplinary Telecommunications and Networking (IJITN), 6*(1), 10–25.

Miles, H. C., Pop, S. R., Watt, S. J., Lawrence, G. P., & John, N. W. (2012). A review of virtual environments for training in ball sports. *Computers & Graphics, 36*(6), 714–726.

Norrby, M., Grebner, C., Eriksson, J., & Bostrom, J. (2015). Molecular rift: Virtual reality for drug designers. *Journal of Chemical Information and Modeling, 55*(11), 2475–2484.

Pantelidis, V. S. (2010). Reasons to use virtual reality in education and training courses and a model to determine when to use virtual reality. *Themes in Science and Technology Education, 2*(1–2), 59–70.

Pappa, G., Ioannou, N., Christofi, M., & Lanitis, A. (2018). Preparing student mobility through a VR application for cultural education. In *Advances in digital cultural heritage* (pp. 218–227). Cham: Springer.

Parsons, S. (2016). Authenticity in virtual reality for assessment and intervention in autism: A conceptual review. *Educational Research Review, 19*, 138–157.

Parsons, T. D., Bowerly, T., Buckwalter, J. G., & Rizzo, A. A. (2007). A controlled clinical comparison of attention performance in children with ADHD in a virtual reality classroom compared to standard neuropsychological methods. *Child Neuropsychology, 13*(4), 363–381.

Powers, M. B., & Emmelkamp, P. M. (2008). Virtual reality exposure therapy for anxiety disorders: A meta-analysis. *Journal of Anxiety Disorders, 22*(3), 561–569.

Rizzo, A. A., Bowerly, T., Buckwalter, J. G., Klimchuk, D., Mitura, R., & Parsons, T. D. (2009). A virtual reality scenario for all seasons: The virtual classroom. *CNS Spectrums, 11*(1), 35–44.

Rothbaum, B. O., Hodges, L., Smith, S., Lee, J. H., & Price, L. (2000). A controlled study of virtual reality exposure therapy for the fear of flying. *Journal of Consulting and Clinical Psychology, 68*(6), 1020–1026.

Rutherford-Morrison, L. (2015). Gender swap virtual reality headsets let you experience what the other gender experiences. Retrieved from http://www.bustle.com/articles/131482-gender-swap-virtual-reality-headsets-let-you-experience-what-the-other-gender-experiences.

Sanchez-Vives, M. V., & Slater, M. (2005). From presence to consciousness through virtual reality. *Nature Reviews Neuroscience, 6*(4), 332.

Schwebel, D. C., Combs, T., Rodriguez, D., Severson, J., & Sisiopiku, V. (2016). Community-based pedestrian safety training in virtual reality: A pragmatic trial. *Accident Analysis and Prevention, 86,* 9–15.

Shih, Y. C., & Yang, M. T. (2008). A collaborative virtual environment for situated language learning using VEC3D. *Journal of Educational Technology & Society*, *11*(1).

Slater, M. (2009). Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. *Philosophical Transactions of the Royal Society of London B: Biological Sciences, 364*(1535), 3549–3557.

Slater, M., & Sanchez-Vives, M. V. (2016). Enhancing our lives with immersive virtual reality. *Frontiers in Robotics and AI, 3,* 74.

Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators & Virtual Environments*, *6*(6), 603–616.

Smith, M. J., Fleming, M. F., Wright, M. A., Roberts, A. G., Humm, L. B., Olsen, D., et al. (2015). Virtual reality job interview training and 6-month employment outcomes for individuals with schizophrenia seeking employment. *Schizophrenia Research, 166*(1–3), 86–91.

Spanlang, B., Normand, J. M., Borland, D., Kilteni, K., Giannopoulos, E., Pomés, A., et al. (2014). How to build an embodiment lab: Achieving body representation illusions in virtual reality. *Frontiers in Robotics and AI, 1,* 9.

Stavroulia, K. E. & Lanitis, A. (2018). Addressing the cultivation of teachers' reflection skills via virtual reality based methodology. In *The Proceedings of ICL2018—21th International Conference on Interactive Collaborative Learning* (pp. 142–153), 25–28 September 2018, Kos Island, Greece.

Stavroulia, K. E., Ruiz-Harisiou, A., Manouchou, E., Georgiou, K., Sella, F., & Lanitis, A. (2016). A 3D virtual environment for training teachers to identify bullying. In *2016 18th Mediterranean Electrotechnical Conference (MELECON)* (pp. 1–6). IEEE.

Stavroulia, K.E., Baka, E., Christofi, M., Michael-Grigoriou, D., Magnenat-Thalmann, N. & Lanitis A. (2018a). A virtual reality environment simulations drug use in schools: effect on emotions and mood states. In *Proceedings of the International Conference on Information Communication Technologies in Education (ICICTE 2018)* (pp. 225– 234). Retrieved from http://www.icicte.org/assets/6.2_stavroulia_-baka_-christofi_michael-grigoriou_-magnenat-thalmann_lanitis.pdf.

Stavroulia, K. E., Baka, E., Lanitis, A., & Magnenat-Thalmann, N. (2018b). Designing a virtual environment for teacher training: Enhancing presence and empathy. In *Proceedings of Computer Graphics International 2018* (pp. 273–282). ACM.

Steuer, J. (1992). Defining virtual reality: Dimensions determining telepresence. *Journal of Communication, 42*(4), 73–93.

Stover, W. J. (2007). Simulating the Cuban missile crisis: Crossing time and space in virtual reality. *International Studies Perspectives, 8*(1), 111–120.

Ting, H. Y. (2013). Fostering creative pedagogy among secondary art teacher training students in Taiwan: Investigating the introduction of possibility thinking as a core of creative pedagogy in a workshop intervention.

Vive Pro—The professional-grade VR headset (2018). Retrieved from https://www.vive.com/eu/product/vive-pro/.

Virvou, M., & Katsionis, G. (2008). On the usability and likeability of virtual reality games for education: The case of VR-ENGAGE. *Computers & Education, 50*(1), 154–178.

Von Hippel, E. (2005). *Democratizing innovation*. MIT press.

Zarraonandia, T., Díaz, P., Montero, A., & Aedo, I. (2016). Exploring the benefits of immersive end user development for virtual reality. In *Proceedings of the International Conference on Ubiquitous Computing and Ambient Intelligence* (pp. 450–462). Cham: Springer.

Zarraonandia, T., Diaz, P., & Aedo, I. (2017). Using combinatorial creativity to support end-user design of digital games. *Multimedia Tools and Applications, 76*(6), 9073–9098.

Zendejas, B., Brydges, R., Hamstra, S. J., & Cook, D. A. (2013). State of the evidence on simulation-based training for laparoscopic surgery: A systematic review. *Annals of Surgery, 257*(4), 586–593.

Chapter 11
MaroonVR—An Interactive and Immersive Virtual Reality Physics Laboratory

Johanna Pirker, Michael Holly, Isabel Lesjak, Johannes Kopf and Christian Gütl

1 Introduction and Motivation

STEM (shorthand for Science, Technology, Engineering, and Mathematics) education in digital environments often still poses a challenge. There is still a lack of STEM graduates (Olson & Riordan, 2012) and, unfortunately, many students still describe STEM fields as *boring and complicated* fields. Thus, STEM learning environments should be designed in a more interactive, engaging, and exciting way to support the learning needs of the new generations (Caprile, Palmén, Sanz, & Dente, 2015). Learners should be supported with interactive and hands-on experiences to help them understand the underlying principles and phenomena of often complicated formulas. Thus, successful STEM education should be grounded in constructivism and motivation is a crucial element to cognition (Sanders, 2008). In the digital age, it is crucial to also support these cognitive themes with digital tools to provide virtual, flexible, as well as mobile forms of such interactive learning experiences. In Pirker (2017), motivational environments are introduced as digital environments, which support learner engagement through principles inspired by game design techniques as well as immersion as key motivators. In this chapter, we present this approach integrated into *Maroon*. Maroon is a virtual e-learning tool to support the needs of interactive and engaging STEM education through the use of immersive technologies such as virtual reality. Maroon is designed as a flexible and extensible e-learning environment, which supports the integration of different interactive learning experiences for different fields. In this chapter, we focus on introducing the virtual reality

---

J. Pirker (✉) · M. Holly · I. Lesjak · J. Kopf · C. Gütl
Graz University of Technology, Graz , Austria
e-mail: jpirker@iicm.edu

M. Holly
e-mail: michael.holly@tugraz.at

J. Kopf
e-mail: johannes.kopf@tugraz.at

P. Díaz et al. (eds.), *Learning in a Digital World*, Smart Computing and Intelligence, https://doi.org/10.1007/978-981-13-8265-9_11

capabilities of Maroon and provide guidelines when creating such interactive and engaging forms of learning experiences. The chapter is built on the results presented in Pirker, Holly, Hipp, König, Jeitler, and Gütl (2017a), Pirker, Lesjak, and Guetl (2017b), Pirker, Lesjak, Parger, and Gütl (2017c), Pirker, Lesjak, Parger, and Gütl (2018) and in the Dissertation (Pirker, 2017).

Contributions. In this chapter, we outline the core principles and deployment forms of the virtual physics laboratory *Maroon* with a focus on the virtual reality build. Furthermore, we provide guidelines based on previous study results for creating educational learning experiences in VR.

2 Background and Related Work

Interesting, flexible, and engaging forms of education are becoming increasingly essential to fulfill the needs of the new generations of learners. The lack of student engagement is a primary reason for missing interest and high failure rates in STEM fields (Reeve, Jang, Carrell, Jeon, & Barch, 2004). The core of this chapter is the investigation of tools and approaches supporting STEM education with a focus on the needs of the new generations.

2.1 STEM Education

STEM (Science, Technology, Engineering, and Mathematics) subjects are becoming increasingly important worldwide and are being seen as the driver for innovation, technological progress, and as a means to understand and protect our environment (Zeidler, 2016). Consequently, STEM education is vital for our society, but many students experience educational approaches in school and at university level as being rather uninspiring, ineffective or too difficult to comprehend. Thus, many universities fail to retain students in pursuing their STEM degrees, as students lack or lose interest in studying such subjects (Olson & Riordan, 2012). To meet the growing demand of STEM professionals worldwide, it is thus necessary to design STEM classes in a more interesting and engaging way.

It becomes increasingly challenging to please the new generation of learners. As a result, pedagogical approaches have transformed from repetitive, fact-based, and procedural knowledge acquisition into learning with understanding and room for self-organization over the last decades (Chang & Guetl, 2010; Thompson, 2015). In particular, in STEM education, approaches such as self-directed learning, active learning, and group-based learning experiences as well as motivational aspects have been increasingly recognized by educational experts and practitioners (Bell, 2016; Delaney, O'Keeffe, & Fragou, 2018). Furthermore, hands-on experiences such as lab experiences or field trips are important components for conceptual and deeper understanding (Avi & Lunetta Vincent, 2004) (Nir).

ICT (Information and Communication Technologies) can support the learning approaches covered above. Blended learning, online learning, and mobile learning experiences are widely used in STEM education; however, there is still much room for improvements (Kanematsu & Barry, 2016; Harandi, 2015). Game-based learning has the potential to raise interest and increase engagement and motivation. These tools may also face issues such as high production cost and inefficient learning experiences (Hamari, Shernoff, Rowe, Coller, Asbell-Clarke, & Edwards, 2016; Jabbar & Felicia, 2015). Hands-on activities, even contextualized learning settings, can be supported by nonlinear storytelling (Cavazza & Young, 2017; Molnar, 2018), simulations and online labs (Potkonjak et al., 2016; Machet, Lowe, & Gütl, 2012). These tools can help students to explore and understand phenomena and contextualize acquired knowledge, but this also requires appropriate didactic approaches and production costs.

Narrowing down to physics, the current application domain of Maroon, this subject forms a core part of STEM education in schools and at universities. Despite being a widely taught subject for a very long time, even in today's modern classrooms, it is still quite challenging to make physics education engaging and exciting to students, many of whom often struggle to understand the underlying scientific concepts behind complex physics phenomena such as electromagnetism, thermodynamics, or quantum mechanics (Scheucher, Bailey, Gütl, & Harward, 2009; Gütl, Scheucher, Bailey, Belcher, Santos, & Berger, 2012). The abovementioned educational approaches and technologies have been adopted, experimented, and adapted in the physics domain of education (Scheucher et al., 2009; Shurygin & Krasnova, 2016; Coca & Sliško, 2017). Selected pedagogical concepts and technologies relevant in the context of the Maroon project are covered in the following subsections.

2.2 Active Learning

One approach to make physics, or science education in general, more engaging is by applying the pedagogical concept of active learning. During active learning, students are being directly involved in the learning process through interactive and collaborative in-class activities (such as group discussions or concept questions), instead of just passively listening to their teacher's lecture. Research from Prince (2004) and Freeman et al. (2014) has shown the effectiveness of the active learning model in improving students' performance and learning outcomes, when compared to more traditional teaching methods such as frontal lectures. By engaging students in the learning process with hands-on experiences, active learning puts the emphasis on developing students' problem-solving capabilities rather than on reciting theoretical concepts or memorizing formulas.

As part of active learning settings, different digital tools and environments can be used to support teaching and enhance engagement, immersion, and motivation of learners. These tools range from interactive visualizations, educational simulations, and entirely virtual or remote laboratories to gamified learning environments and whole virtual, collaborative worlds.

Simulations and visualizations are useful to make otherwise invisible phenomena (e.g., field lines) visible to the user and can facilitate the understanding of relations between physical concepts and the corresponding physical laws or general formulas. Computer-based simulations and interactive visualizations enable students to observe physical processes in detail and allow them to experiment with various system parameters or conditions at their own pace. Through simulations, students have the possibility to stretch time and space and to conduct experiments that would be too dangerous, expensive, or even impossible in real life (Lunce, 2006).

The benefits of using simulations to teach physics have been indicated in previous research, with simulations applied to explain Newtonian mechanics (Jimoyiannis & Komis, 2001) and concepts of electromagnetism (Dori & Belcher, 2005) in a more effective way. In contrast to setting up traditional experiments in a physical laboratory, the dynamic nature of digital simulations makes them a safer, time-saving, and cost-efficient method of instructing students in physics classes (Wieman & Perkins, 2005).

Another form of conveying physics knowledge in an interesting and engaging manner is through the use of **virtual laboratories**. Various types of virtual laboratories have been developed so far. The virtual lab simulation software "LABSTER"[1] is one of the more well-known virtual laboratories in use nowadays and provides lab experiences for different science and engineering disciplines on a subscription basis. With "Virtual Labs",[2] the Indian government has also established a learning management system to unite various simulation-based virtual labs and remote-triggered virtual labs on one common website, providing easy access to these resources. In Denmark, the "Virtual Laboratory",[3] a virtual environment for biotechnology laboratory experiments, has been developed by the BioTech Academy.[4] This setup offers the possibility to experience biotechnological research tasks such as designing genes and growing yeast cells in a virtual, yet realistic setting.

The use of virtual laboratories in science education has also been reported to positively impact students' attitude toward learning, for example, in physics classes (Aşıksoy & Islek, 2017) and in chemistry classes (Tüysüz, 2010).

Remote laboratories are another technology-enabled tool, which is being applied in active learning settings, especially for virtual science education. While virtual laboratories rely on software simulations of a lab environment, remote laboratories make use of Internet technologies to connect students to a physical lab located in a different location than themselves (Chen, Song, & Zhang, 2010). Through the Internet, students can then remotely access, control, and conduct experiments with real equipment, without them actually being physically present in the lab. Remote laboratories combine the physical and virtual aspects of laboratory environments and allow for worldwide sharing of resources and lab equipment. Through camera feeds

---

[1] https://www.labster.com/.

[2] http://vlab.co.in/.

[3] http://virtueltlaboratorium.dk/.

[4] http://www.biotechacademy.dk/.

or other visualization techniques, they offer a digital, virtual view of the physical laboratory setting and can be seen as a technology-enabled extension of traditional hands-on laboratories. In a corresponding study by Broisin, Venant, and Vidal (2017), it is shown that activities within the remote system have positive effects on student engagement.

In a large-scale study with 306 participants, Corter, Nickerson, Esche, Chassapis, Im, and Ma (2007) compared three different types of labs: simulated (virtual) laboratories, remote laboratories, and hands-on laboratories. By evaluating students' performance via multiple choice tests on lab topics, the authors have concluded that students' learning outcomes in the remote or simulated setting are at least equally high or even higher than in traditional, hands-on laboratories. Apart from investigating the educational effectiveness of alternative lab technologies through conceptual knowledge questions, Corter et al. also asked students about their subjective perception and preference for the different lab experiences. Students preferred the hands-on work in physical laboratories, as their actual physical presence and the easier possibility for teamwork helped to contribute toward a more engaging experience. Nevertheless, virtual and remote laboratories were rated by students as the more convenient and reliable solution, allowing individuals to work at their own pace.

In an extensive literature review by De Jong, Linn, and Zacharia (2013), the authors elaborate on similarities and differences between physical and virtual laboratories, each of which can be beneficial for certain use cases. Whereas physical laboratories are usually better suited for acquiring practical lab skills and interacting face-to-face with real equipment and other students in a team, virtual laboratories have the advantage of being easily adaptable (varying degree of realism, different parameters) and also accessible by many students at the same time, who are then able to observe and explore otherwise hidden phenomena through visualizations and simulations. Ultimately, the combined use of both physical and virtual laboratories is recommended to maximize the benefit for learners.

2.3 Technology-Enhanced Active Learning

A special form of active learning is the so-called "Technology-Enhanced Active Learning" (TEAL)—a pedagogical model which was first established to enhance freshman physics classes at Massachusetts Institute of Technology (MIT) in 2001 (Dori & Belcher, 2006). The TEAL approach focuses on collaborative, interactive learning by including conceptual questions, three-dimensional simulations, and visualizations as well as hands-on experiments and group discussions during in-class lectures. It requires a specially designed classroom with shared working space for small groups and desktop experiments, and it uses the TEALsim software framework for simulations and visualizations (Pirker, Gütl, Belcher, & Bailey, 2013). In comparison with traditional lecturing formats, the TEAL teaching method has been shown to positively impact students' comprehension as well as retention of physical concepts (i.e., about electricity and magnetism; Dori, Hult, Breslow, & Belcher, 2007).

Building upon this TEAL model, a virtual learning environment for physics education, called the “Virtual TEAL World”, has been developed in 2013 (Pirker, 2013). This work integrates the TEAL approach into an immersive, virtual environment with three-dimensional simulations and cooperative scenarios, where students can collaborate to conduct experiments and discuss result (Pirker, Berger, Guetl, Belcher, & Bailey, 2012). The Virtual TEAL World acts as the more cost-effective version of the original TEAL environment at MIT, and as such, it is also suitable for distance learning.

2.4 Game Design Concepts in Education

The use of games or game design elements in educational environments has proven to be advantageous to improve learner’s motivation and engagement, particularly in STEM subjects where “very specific content can be targeted” (Randel, Morris, Wetzel, & Whitehill, 1992). In Pirker and Gütl (2015), a framework for gamification of science simulations in STEM fields is presented, demonstrating that gamification technique—when applied properly—can enrich new or existing simulations and result in a more engaging and motivational experience for learners. In the field of biotech education, a gamified and playful version of a virtual laboratory has been developed and evaluated by Bonde et al. (2014). Their study indicates that gamified laboratory simulations lead to an increased level of motivation within students, who then also manage to achieve better learning outcomes (76% higher test scores, compared to conventional teaching). It is recommended to integrate gamified simulation along with traditional lecturing to optimize learning effectiveness as well as motivational levels among learners.

Additionally, the design of educational environments can not only be enhanced by including game design elements for playful learning but also by regarding the factors immersion, presence, and flow as motivational drivers. These factors are not only important to engage players in (video) games (Brockmyer, Fox, Curtiss, McBroom, Burkhart, & Pidruzny, 2009) but are also helpful to create captivating learning experiences that keep learners engaged.

Flow is the feeling of being completely involved and absorbed in a certain activity and manifests itself as a mental state of full concentration and clear focus. It has been described as the “optimal experience,” whenever a person’s skills are met with an adequate type of challenge (Csikszentmihalyi, 2008). A more detailed elaboration on the term “flow” and its various aspects can be found in Csikszentmihalyi and Csikszentmihalyi (1992). *Immersion* occurs when someone feels like being a part of a (digital) experience (Brockmyer et al., 2009). In classroom settings, a low level of student engagement or missing immersion can be remedied through the use of virtual reality (VR) experiences, which allow students to interact more directly with digital content. In the context of virtual environments, *Presence* is the feeling of actually “being there” and can be defined as “experiencing the computer-generated environment rather than the actual physical locale” (Witmer & Singer, 1998). To distinguish it from to immersion, the presence can be seen as the (individually varying) human reaction to feeling immersed (Slater, 2003). While immersion can be objectively assessed (as it is made possible by technical features of a system), the presence is a rather subjective feeling—the same immersive system may still result in different levels of presence within different users, and vice versa.

2.5 Virtual Reality in Education

In order to create a feeling of immersion and engagement, the potential of emerging virtual reality (VR) technologies can be used to create interesting learning experiences for today's generation of students. Virtual reality uses special software and hardware to immerse users in a simulated, three-dimensional environment, where they can experience the feeling of actual physical presence within a virtual world. Apart from gaming and entertainment, a wide range of other application areas for VR has opened up so far, ranging from medical sciences (Górski, Buń, Wichniarek, Zawadzki, & Hamrol, 2017), therapy (Lindner et al., 2017) and sports (Neumann et al., 2017) to architecture (Portman, Natapov, & Fisher-Gewirtzman, 2015), manufacturing (Choi, Jung, & Noh, 2015), higher education (Freina & Ott, 2015), and many more areas. Another innovative use of VR is in the creation of 360° VR films, such as the movies created by the nonprofit ANGARI foundation to educate students and the broader community about ocean research and the marine environment (available online[5]).

Through the use of virtual reality devices and 3D engines such as Unity,[6] it is possible to design more engaging environments that enable the learner to enter a fully, or partly immersive, virtual world. Modern VR technologies enable scenarios with different degrees of immersion (such as room-based VR setup vs. head-mounted VR gear). Depending on the VR environment, users' perception of activities at hand as well as their experienced emotions may differ. Therefore, it is important to take into consideration different design aspects for different VR environments, as described by Settgast et al. in their evaluation (Settgast, Pirker, Lontschar, Maggale, & Gütl, 2016). In a preliminary study, these authors also use different VR scenarios to investigate levels of cybersickness, a condition which manifests itself in a feeling of discomfort, disorientation, nausea, or even vomiting, either while or after experiencing VR.

---

[5] http://angari.org/film/.

[6] https://unity3d.com/.

2.5.1 Virtual Reality Devices

Current state-of-the-art virtual reality devices such as the HTC Vive,[7] the Sony Playstation VR,[8] and the Oculus Rift[9] have become increasingly affordable and widely available to the general public. These head-mounted displays (HMDs) offer a more immersive VR experience with room-scale support, whereas mobile VR solutions such as the Samsung Gear VR headset[10] (compatible with Samsung Galaxy smartphones) or the Google Cardboard[11] provide a more portable, flexible, and lightweight way of experiencing virtual reality. Especially, these cost-effective, mobile VR solutions have made VR technology more attractive for use in classrooms (Olmos, Cavalcanti, Soler, Contero, & Alcañiz, 2018).

2.5.2 Virtual Reality Laboratories

Nowadays, more and more virtual reality laboratories are being developed and successfully put to use for training and education scenarios, as academic institutions and enterprises alike have recognized the added value of incorporating VR technology. Some better known examples of physical laboratories hosting various virtual experiences include the Virtual Reality Laboratory at NASA[12] and the Immersive Virtual Environments Laboratory at University College London.[13]

In contrast, virtual laboratories in VR that are modeled after an actual laboratory with real equipment while making use of consumer VR devices are still not as prevalent. Recently, researchers at Wentworth Institute of Technology have created the "Virtual Electronics Laboratory", which is modeled after the institute's real laboratories on-site. It has been designed in Unity3D for use in room-scale VR with the HTC Vive. The effectiveness of this virtual laboratory as an educational tool was evaluated in a recent study with 45 participants (McCusker, 2018). Here, the authors demonstrate that a combined approach of teaching students in both the VR and the real version of the laboratory produces the best outcome in assessment quiz scores.

Some other commercially available examples of complete laboratory environments in VR can also be downloaded from the Steam Store,[14] which generally offers a variety of VR applications for different devices. For example, "The Lab"[15] is a room-scale VR experience developed by valve to showcase the possibilities for interaction and gameplay with the HTC Vive through various real-life-like scenarios

---

[7] https://www.vive.com/eu/.

[8] https://www.playstation.com/en-us/explore/playstation-vr/.

[9] https://www.oculus.com/rift/.

[10] https://www.samsung.com/global/galaxy/gear-vr/.

[11] https://vr.google.com/cardboard/.

[12] https://www.nasa.gov/centers/johnson/partnerships/eddc/ra/virtual-reality-laboratory/.

[13] https://vr.cs.ucl.ac.uk/.

[14] https://store.steampowered.com/.

[15] https://store.steampowered.com/app/450390.

(e.g., repairing a robot, performing a medical scan, or shooting arrows). Another product showcasing the educational use of VR is “The VR Museum of Fine Art”,[16] where users can explore a very realistic museum and view life-sized paintings and sculptures up close.

The contribution presented in this paper—“MaroonVR”—is one major example of an interactive physics laboratory in VR, running on different VR devices. As demonstrated in a comparative study (Pirker et al., 2017a), different laboratory setups in VR result in different user experiences. For the study, the following three variants of the “Maroon” laboratory setup were compared among each other: a multiuser mobile VR setup, a room-scale VR setup, and a non-VR desktop-based version of Maroon.

In light of the above, this book chapter’s main contribution—“Maroon” itself—-can also be seen as a valuable, VR-enabled tool for e-learning and active learning. It has been designed as an interactive virtual physics laboratory that allows students to engage and interact with various physics experiments, while being fully immersed in their virtual surroundings. While this chapter mainly describes Maroon as a tool to support learning physics, it is designed as extensible platform supporting different learning experiences for different subjects. The following section describes the design and implementation of Maroon in more detail.

3 Design and Implementation of Maroon

Maroon is an interactive immersive physics laboratory developed in Unity3D,[17] a game engine which allows to build and deploy a high-quality 3D environment across mobile, desktop, and VR platforms. The lab is designed to support the flexible integration of different interactive learning experiences. The main room (see Fig. 1) represents a virtual, three-dimensional table of content of the different learning experiences. To start a specific learning experience, the user would approach one of those stations (illustrated with a pink marker) and would get teleported to a new room which represents the specific learning experiences with the learning content, simulations, or experiments.

The current version of the lab is designed as learning experience to learn about electromagnetic and electrostatic physics concepts through different experiments and visualizations. In this three-dimensional experiment, various experiments can be tried out, which are often difficult, too expensive, or too dangerous to perform in the real world.

Maroon imitates a classic laboratory with different stations which represent experiments or activities (see Fig. 1). The version we introduce in this chapter contains six electromagnetic and electrostatic experiments as well as one wave experiment. Users can start the experiments and the activities using the checkpoints in front of the

---

[16] http://store.steampowered.com/app/515020/.

[17] https://unity3d.com/.

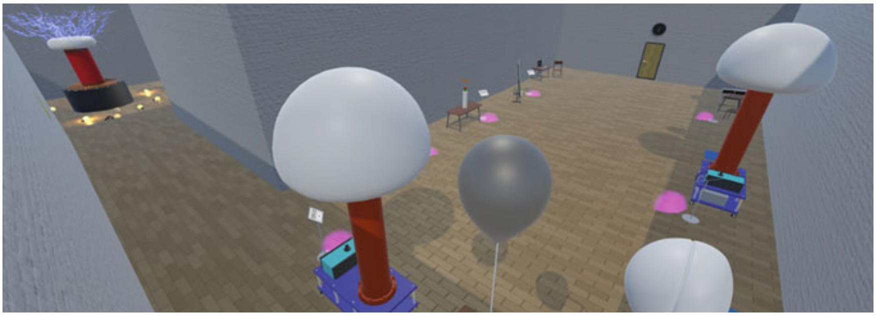


Fig. 1 Lab overview

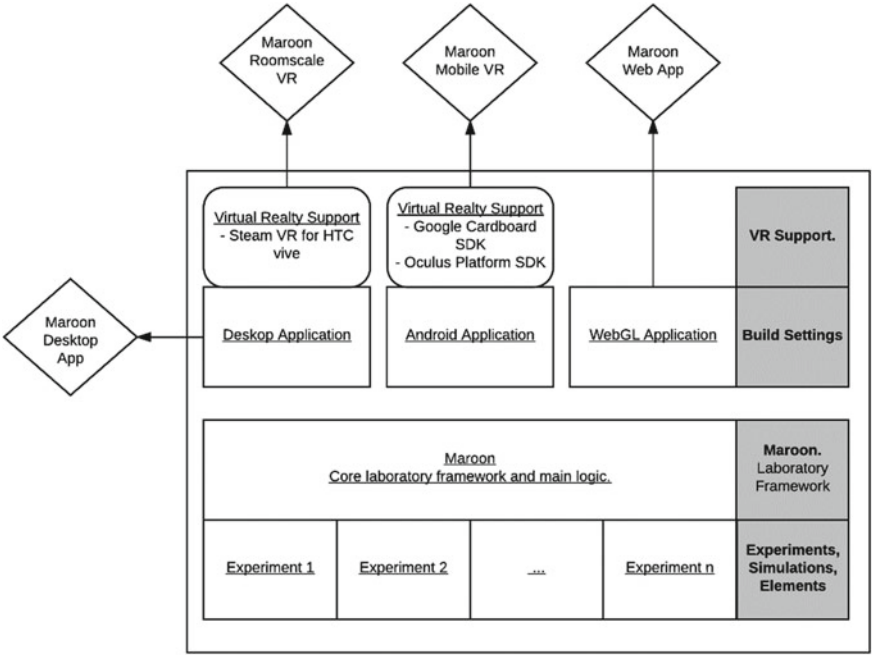


Fig. 2 Overview of the different versions of Maroon

experiment stations. In this chapter, we introduce four variants of Maroon (Maroon desktop, Maroon room-scale VR, Maroon mobile VR, and Maroon multiuser) with the goal to evaluate different aspects such as usability, immersion, and engagement. To understand the interaction of users with different forms of virtual learning experiences, we evaluated the different variants of Maroon with focus on usability, engagement, and learning experiences. A conceptual overview of the different versions of Maroon, each supporting different forms of engagement (e.g., through activities or through social interaction), is illustrated in Fig. 2.

In the following sections, we introduce and describe these different versions of the Maroon lab.

3.1 Maroon (Desktop)

Maroon as a desktop-based variant resembles a classic computer game from the first-person perspective. The control is done via keyboard and mouse. The mouse simultaneously performs several functions: it is used to determine the view direction freely in all directions and thus the direction of movement and to interact with the environment. The arrow keys are used to perform forward and backward movements. Users can select one of the experiments by moving to one of the experiment stations. If they are close enough to the checkpoint, they can enter the specific experiment. The experiments are designed to show the user the underlying physics concepts. Since it is very difficult to understand invisible phenomena, Maroon provides various visualizations to make it much more easier to understand. In addition, some experiments can be controlled via a graphical user interface. Users can vary different physical parameters by control elements such as sliders to see how these parameters impact the experiment outcome.

3.2 Maroon Room-Scale VR

Maroon room-scale VR is an extension of Maroon, enabling a room-scale virtual reality experience. Maroon room-scale VR has been specially designed to run on two distinct platforms, the HTC Vive, and the Oculus Rift. These two variants of Maroon Room-Scale VR are currently under development and will be described in the following subsections.

3.2.1 Maroon Room Scale for HTC Vive

The first room-scale variant of the Maroon laboratory was custom-built to run on the HTC Vive. To build a room-scale VR solution in Unity3D for the HTC Vive, we used the official SteamVR[18] plugin and the Virtual Reality Toolkit[19] (VRTK). The HTC Vive allows users to freely move around a play area. The user's movement is tracked and mapped one-to-one into the virtual 3D space. Motion-tracked handled controller allows to interact with virtual objects and environments. To determine the exact position and orientation in reality, each hardware component has several photosensors which receive laser beams from the base stations. The time it takes for the beam to

---

[18] http://store.steampowered.com/steamvr.

[19] https://vrtoolkit.readme.io/.

reach these sensors provides information about the position of the hardware. The controllers are equipped with 24 sensors, a multi-function trackpad, a two-stage trigger, and a haptic feedback feature. Each controller button can be programmed individually to enhance the user interaction (HTC, 2018). Since the space in the real room is limited, users have to deal with a different kind of movement so that they can travel greater distances in virtuality. Teleporting has become a standard in VR applications. It enables a fast and free navigation for the user, without getting sick. For teleporting, users have to press the touchpad on one of the controllers, which then shows a colored beam pointing to the desired target. Experiments and activities are started using the information panels in front of the stations which act as a portal into the experiment environment. Each experiment was specially designed for use in VR. Users can change various specific parameters and visualizations using a virtual control panel. Any interactable object used for the experiment is located in such a way that it can be easily reached without having to teleport. To make it easier to recognize such usable objects, they are being highlighted in color when touched.

3.2.2 Maroon Room Scale for Oculus Rift

The second variant of Maroon Room Scale is currently still under development and was built to run on the Oculus Rift. It contains almost all experiments available on the HTC Vive variant, but it comes with a completely redesigned user interface and a native Oculus Rift experience. For development, the VRTK and the Oculus Utilities for Unity[20] are being used.

The Oculus Rift uses an Infrared Radiation (IR)-LED array on the headset that is being tracked by one or multiple camera(s). Therefore, the movement area is restricted by the sight of the camera(s)—this setup is called Constellation (Foxlin, Harrington, & Pfeifer, 1998). The Oculus Rift needs at least two tracking cameras, called the Oculus Sensors, to enable room-scale VR support. The Oculus Rift headset includes three sensors, namely, a gyroscope, an accelerator, and a magnetometer. The combination of these three sensors allows for accurate tracking across all three spatial dimensions. For grabbing objects in VR, two wireless Oculus Touch controllers are used, which can also provide haptic feedback to the user.

The Oculus Rift version of Maroon VR features player collision with objects. Loading a specific experiment is done by pressing the “Enter” button on a console, which also features a small level preview, as depicted in Fig. 3. When using synchronous loading of experiments, the game freezes while loading the new scene, which can cause motion sickness. To prevent this, we load the experiments asynchronously in the background. Once a level has finished loading, it can be accessed by going through a lock. Such a lock can be seen behind the marble in Fig. 3. Figure 4 shows a loaded level. The levels themselves are similar to the levels of the HTC Vive, but the user controls are adapted so they can be used with the Oculus Rift.

---

[20] https://developer.oculus.com/downloads/package/oculus-utilities-for-unity-5/.

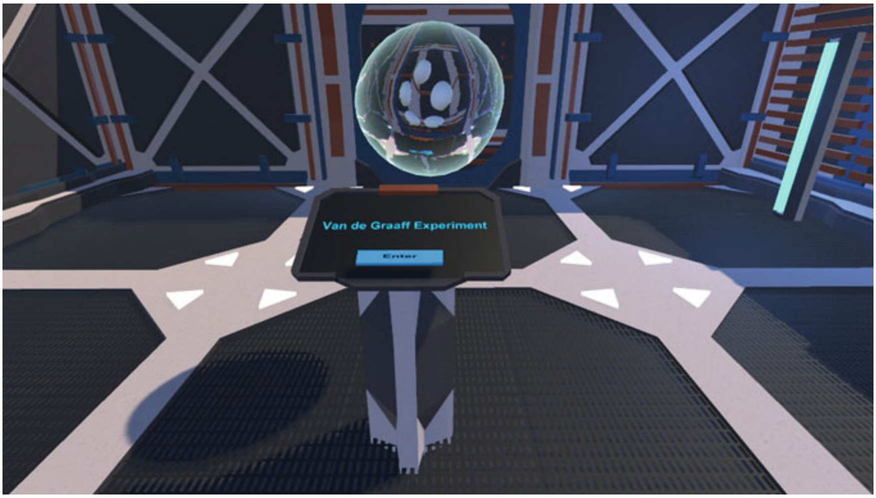


Fig. 3 Console for selecting a level in Maroon VR for Oculus Rift. The marble shows a preview of the level

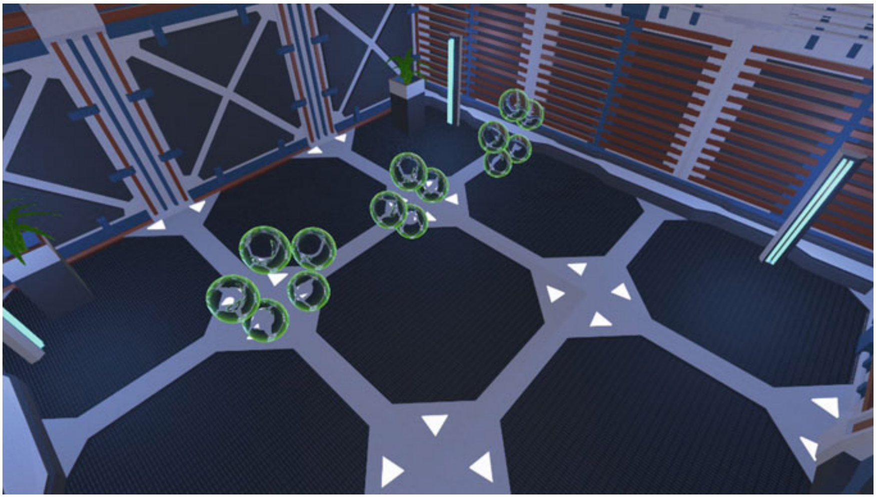


Fig. 4 A loaded experiment in Maroon VR for Oculus Rift

3.3 Maroon Mobile VR

Maroon Mobile VR is also based on Maroon and was developed for the Samsung Gear VR. It is a mobile virtual reality headset designed to work with Samsung Galaxy smartphones. The graphical output is done by the smartphone, while the Gear VR headset device provides buttons, sensor data, and optical elements. A combination

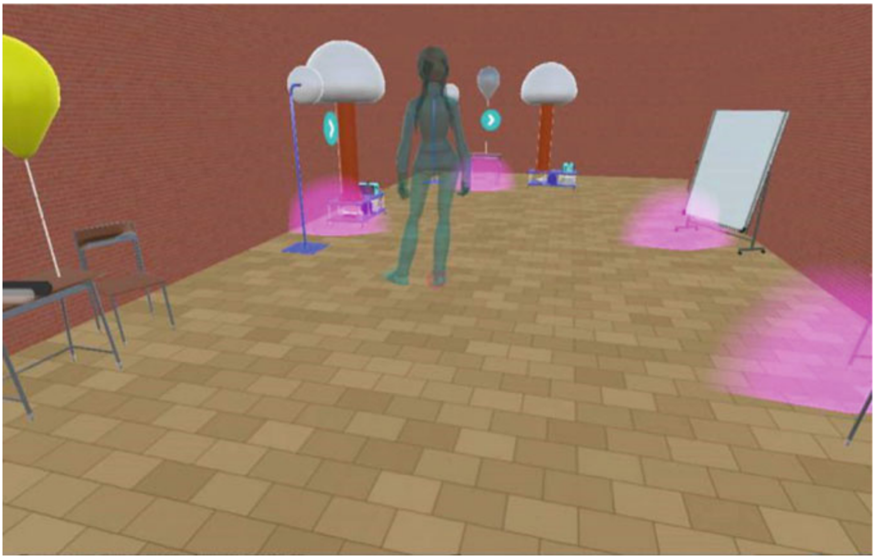


Fig. 5 Maroon mobile VR

of view direction, a virtual avatar, and a touchpad on the side of the headset allows the user to control and interact with the environment. The avatar (see Fig. 5) grants free movement within the lab by teleporting the avatar to different locations. The user orientation is then set to the orientation of the avatar. Users can start simulations and interact with them by moving the gaze cursor to an interaction button. In VR applications, constantly high frame rates are necessary for a comfortable user experience. Since mobile devices are limited in their performance (Gear VR: 50–100 draw calls per frame and 50–100 k polygons per frame Pruett, 2015), we reduced the complexity of calculations and 3D models without losing information about the experiments. This leads to a similar realistic user experience as in room-scale VR.

3.4 Maroon Multiuser

While the previously presented variants of Maroon focus on the individual experience, we have also designed different multiuser variants of Maroon. Learning can be very successful if students learn from each other and exchange knowledge and experiences. This form of learning has great potential, especially in virtual learning environments. Through the integration of social interactions, engagement should be deepened. For this purpose, we developed a network manager which adds server–client communication and synchronization to Maroon. Students join a multiuser space and work together on experiments for a better understanding. During the experiments, each user action is synchronized between the participants. Every student always sees the same state of the experiment and can discuss it together with the other students. In the desktop version of Maroon, the main communication is done via chat and can be used for e-learning sessions. In contrary, the mobile variant is designed for a cooperative VR classroom experience. Therefore, no chat functionality is provided. During the experiments, students can talk to each other in the classroom. In a future version, a VOIP integration is planned to support remote learning scenarios. Currently, there are two playable modes: First, the free mode which allows users a free interaction with the learning environment; and second, the streaming mode which supports a guided learning experience where one user (e.g., a teacher) controls the experiment while the other users (e.g., students) are watching. After the guided session, the control can be released to let students explore the experiment themselves at their own pace.

3.5 Simulations and Experiments

In this section, we want to introduce the various simulations and experiments which are already implemented in Maroon. The following experiments are all included in the HTC Vive version of MaroonVR. The other versions contain only a subset of the existing experiments.

3.5.1 Van de Graaff Generator

A Van de Graaff generator is an electrostatic generator and converts mechanical energy into electrical energy. It is one of the most frequently used devices for physics teaching experiments. A rotating insulating belt will be electrically charged by friction. The electrical charge is transported by the movement of the belt into the large metallic hollow ball.

There are currently two experiments in Maroon which deal with a Van de Graaff generator. The first one demonstrates the electric field between the generator and a grounding sphere. The Van de Graaff generator is charged by holding the trigger button on the controller. Users can change the distance between the two objects to see how the frequency of the discharges changes. If the generator stores enough energy, it produces a visible spark, as illustrated in Fig. 6. The second experiment shows a balloon placed between a Van de Graaff generator and a grounding sphere. Users can observe the behavior of the balloon by charging the generator (see Fig. 7).

3.5.2 Falling Coil and Faraday's Law

In the falling coil experiment, a small magnet is positioned some distance above the table and a conducting nonmagnetic ring is then dropped down onto it. If the coils enter the magnetic field of the magnet, a current is induced. Once there is a current

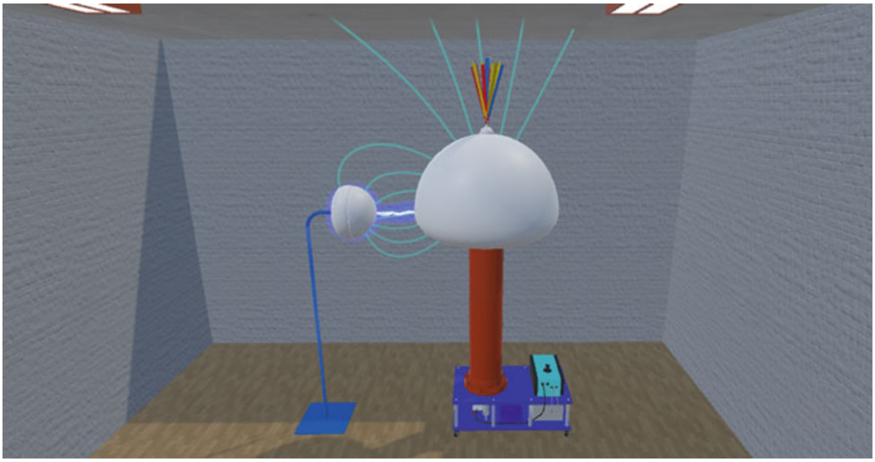


Fig. 6 Van de Graaff generator–discharging

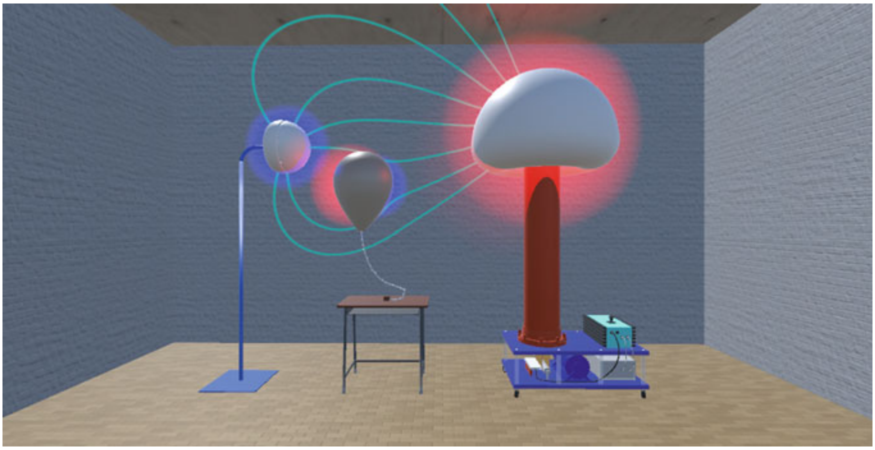


Fig. 7 Van de Graff generator with balloon

running through the ring, it has its own magnetic field which then interacts with the magnetic field of the magnet and applies an upward force to the coil that pushes it back up. The ring has a specified mass, a resistance, and self-inductance, and the magnet has a magnetic dipole moment. Users can change these parameters using control panels to see how the magnetic flux and the induced current are changing correspondingly. Furthermore, users can activate different visualizations like field lines, a vector field, and the iron filling visualization (see Fig. 8). This allows the user to recognize invisible phenomena and thus, get a better understanding of the underlying magnet field.

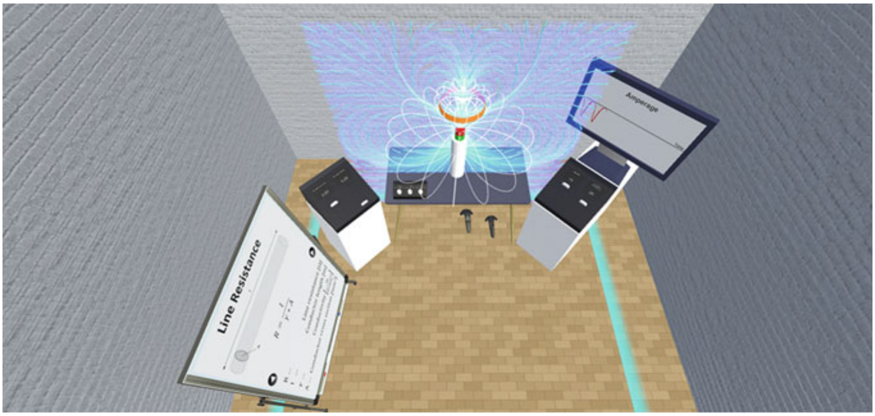


Fig. 8 Falling coil experiment

The Faraday's Law experiment is very similar to the falling coil experiment. It shows the interaction between a coil and a magnet, both constrained on the horizontal axis. When users move the magnet themselves, the changing flux through the coil leads to current into the coil which is displayed to the user as a graph. The special feature in this experiment is that the user can also feel the acting force through haptic feedback which corresponds to the force. This gives the user an "extra-dimension" for an even better experience.

3.5.3 Capacitor

A capacitor is an electrical component which consists of two electrically conductive surfaces which are separated from each other by an insulating material, the dielectric. It stores electric charge and the associated energy in an electric field. The stored charge per voltage is called electrical capacitance which depends on the plate distance, the overlapping area, and the dielectric. Users can change these parameters to see how each parameter affects the capacitance. The resulting capacitance value is shown to the user on the display. By clicking the play button, the capacitor is being charged up to the given voltage. The charging process is illustrated as a graph on the display and through charges that move from one plate to the other plate. The color of the plates indicates how positive or negative they are charged. Users can also observe the behavior of charges in the electric field by placing them into the field. The underlying electric field can be visualized using field lines and a 3D vector field visualization. Figure 9 shows the design of the capacitor experiment.

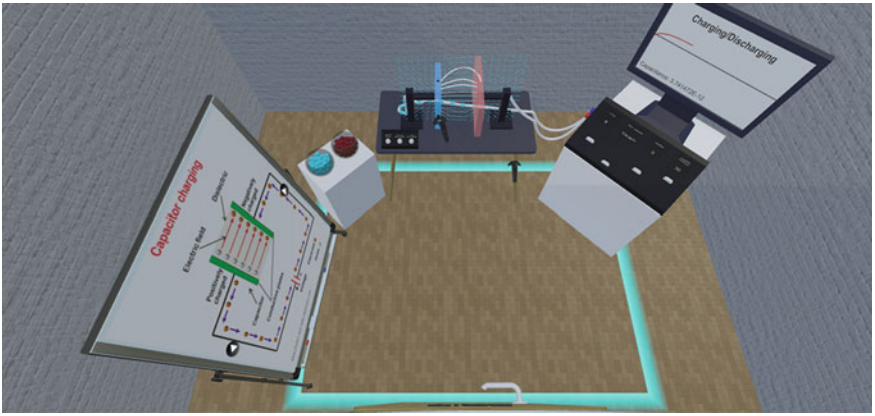


Fig. 9 Capacitor experiment

3.5.4 Huygens Principle

The Huygens Principle experiment is one of the first experiments in Maroon that does not deal with electromagnetism. It shows the physical model of diffraction, which states that every point of a wavefront can be seen as a starting point of a new wave, called elementary wave. The new wavefront results from the overlaying elementary waves. To illustrate the waves, we decided to use a basin filled with water, as shown in Fig. 10. To show diffraction, a slit plate is placed into the basin. Behind this plate, the user can observe the interference pattern generated by diffraction of the wave propagation at the slits. Users can change the wave amplitude, the wavelength, the wave frequency, and the propagation mode to see how these parameters affect the interference pattern behind the plate. The user can also replace the used plate with other plates which have more or fewer slits. This leads to different interference patterns. For a better wave illustration, the wave color can be freely changed.

4 Studies and Findings

To understand the interaction of learners with different versions of Maroon, we have conducted several user studies. In this chapter, we summarize the finding of these studies. Details to the studies can be found in the publications (Pirker et al., 2017a, b, c, 2018) and in the Dissertation (Pirker, 2017).

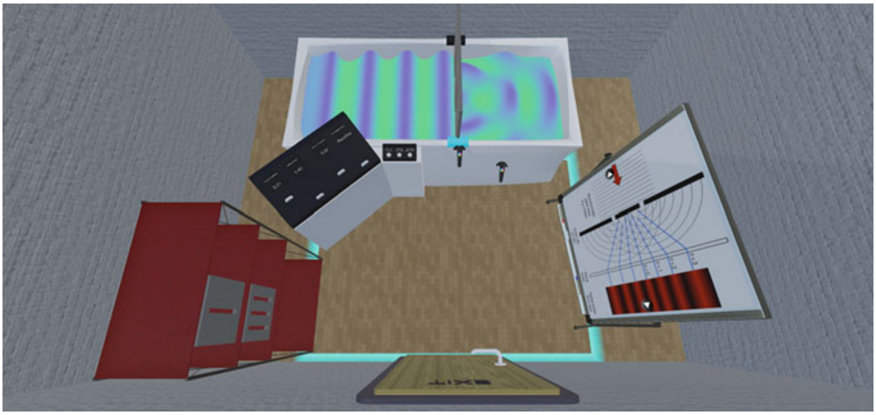


Fig. 10 Huygens principle

4.1 Analysis Room-Scale VR

In Pirker et al. (2017b), we investigated factors such as engagement and immersion of learners while interactive with the Maroon VR supported by the room-scale VR variant with the HTC Vive. In a study with 19 participants between 18 and 53, most of them being students, we were interested in evaluating the overall user experience with learning in a room-scale setup with a focus on the learning experience, useful learning scenarios, engagement, immersion, and user interaction. In this study, we found that users recommend using such environments for more engaged and also more focused learning experiences. Participants stated that it is especially well suited for experiments and simulations which are otherwise too dangerous, invisible, or too expensive. Immersion has been outlined as a strong factor to enhance the concentration when learning in a digital environment. The participants in this study described Maroon as a valuable tool to support learning in classroom scenarios in addition to traditional lectures. It was also found that "realistic" graphics and environments are not essential for creating an immersive and engaging experience.

4.2 Analysis Room-Scale VR Versus Mobile VR

In Pirker et al. (2017a) and in the extended Journal version (Pirker et al., 2018), we were interested in identifying differences between the room-scale variant of Maroon and the mobile VR version. We conducted an A/B study with a total of 17 participants between 23 and 27 years old with a focus on comparing key elements of immersion engagements and identifying application scenarios for the two different setups and investigating interaction design elements for the room-scale and the mobile variant. The results indicate that the room-scale setup was rated as a more realistic experience than the mobile version and scores better when looking at elements supporting engagement such as flow, absorption, or immersion. Users noticed that immersion helped them to focus and remember the learning content better. Both virtual reality setups were described as more engaging and interesting when compared to traditional setups. The room-scale variant was described as more immersive also due to interactive scenarios involving a more intuitive interaction with the experiments through the controllers. However, the mobile version was described as a more flexible learning tool and a good supplement for blended learning environments.

4.3 Analysis Room-Scale VR Versus Computer-Based Experiences

In a final study, described in Pirker et al. (2017c), we compared the VR room-scale experience with a traditional computer-based experience with the goal to identify advantages, disadvantages, and application scenarios of the different technologies. The study was designed as an A/B study with 20 participants. The focus was to compare the two setups based on elements such as immersion, engagement, usability, and the learning experience. We found that traditional computer-based setups are better to support tasks such as reading or note-taking. The VR variants instead allowed a more natural interaction with experiments and kept students engaged and focused on the learning activities. To support engagement in computer-based experiences, a more guided step-by-step experience is suggested. In a VR setup, a more exploration-based approach is suitable.

5 Design Principles for Educational Environments in VR

Based on the findings from the design process as well as the user studies described in the previous sections, we can describe the following design principles to support educational activities in virtual reality setups:

Concentration through immersion

As the new generations are easier to distract from the main learning task, immersion has been identified as an important element to support concentrated learning. In the virtual reality environments, learners are not distracted by instant messengers or similar typical procrastination activities. Thus, it is crucial to support, on the one hand, design elements supporting immersion in VR, on the other hand, provide learners all tools necessary for the learning experience (e.g., a notepad or learning material) so that they do not interrupt their VR learning experiences.

Objectives for self-regulated learning

For self-directed learning scenarios, it is crucial to support learners through a clear objective design in the virtual environment to support flow and engagement. Next steps should be described in a clear well and the goal and the progress toward the goal should be defined. Small tasks followed by constant feedback are enabling a flow experience. Additionally, it is crucial that the learning task difficulty (the challenge) is in line with the current skill level of the learner to avoid boredom by too easy tasks or anxiety by too hard tasks. This supports immersion as well as a flow experience.

Support of different forms of immersion

Different authors have described different forms and definitions of immersion. In Pirker (2017), four forms of immersion have been identified, which can be used to create a more engaging experience: First, tactical immersion through activity design (e.g., through challenges), second, strategic immersion through activities involving solution finding and optimization, third, narrative immersion through the creation of interesting stories, characters, or environments, and lastly, spatial immersion (also presence), which can be created through technology design. To create a high level of engagement and immersion, different activities and design elements should be included.

Allow Exploration

Especially in room-scale VR environments, exploration and playful interactions with the environment have been identified as important design elements. Users should be able to interact with the environment in a natural way, explore, and find interesting new items or small activities. Natural interface design helps to allow a natural interaction with the environment. Simple elements, such as a clock, help users to immerse themselves into this new environment. For Maroon, one “tutorial” room supporting the interaction with different items has been designed. This room is designed to let users explore elements and the environment and helps them learn how to interact with the environment in a playful way. This helps them to focus later on the learning activities instead of learning how to use controls and interact with experiments.

New Forms of Interactions

Virtual reality supports new forms of interactions with in-world items and the environment. Classical user interfaces would not be useful and would minimize the feeling of immersion. Thus, new and more natural forms of interactions and interaction hubs should be designed. While in the classical computer-based setup users would interact with experiments through traditional GUIs, in the VR variant, the user interacts with a three-dimensional control panel with levers, buttons, and switches. To leave a room, users would need to press the door handle. To leave the application of the lab, users would need to exit through the main door. In the experiment “Huygens principle”, users would need to manually switch the slit plate by pulling out the old one and switching it to a different one, which they would find in a shelf. Compared to classical user interfaces, it is crucial to provide natural interactions, which are similar to real-work interactions. This also supports the feeling of immersion.

Social Interactions in VR

Social interactions in educational virtual reality setups are still a challenge in terms of user interaction design. It is crucial to respect the personal space of other avatars and prohibit improper interactions with other avatars. For the multiuser mobile version of Maroon VR, we have used a nonhuman character design. Users are represented as a neutral robot avatar and cannot cross the personal space of others. This way learners can focus on the learning experience.

6 Conclusion

As mentioned in Gaspar, Morgado, Mamede, Manjón, and Gütl (2018), it is crucial to continue research into immersive environments in order to enable a widespread use of this technology, especially for educational purposes. Future research should look into the following main issues: (1) how immersive environments such as MaroonVR can be made easily available and accessible to a wide range of teachers and students, with varying levels of digital skills and equipment; (2) how engaging and interesting content for MaroonVR or similar environments can be produced, adapted, or reused, by software experts as well as by educators themselves; and (3) how the large-scale deployment, automatic assessment, and efficient management of such virtual e-learning systems can be implemented, especially when different (VR) platforms are involved.

In this paper, we have described Maroon with a focus on its virtual reality capabilities and summarized previous studies conducted with different forms of Maroon such as room-scale VR, mobile VR, and computer-based variants. Based on design and implementation experiences as well as the user studies, we were able to identify various design guidelines to create educational experiences in virtual reality setups. Immersion and engagement have been identified as key elements to support learners. Immersion has also been shown as a valuable new tool to support concentration. Especially a new way of interaction design with in-world environments and objects is crucial to support an immersive experience. Mobile virtual reality environments are good tools to support in-class learning experiences which are designed for short virtual experiments.

Summarizing, we believe that virtual reality is a powerful tool, which can provide new more engaging and interactive forms of learning and training. However, it is crucial to not design these environments the same way traditional user interfaces are designed to use the full capability of the setups and create a high level of immersion.

Acknowledgements We would like to thank MIT's John W. Belcher for his valuable expertise in pedagogical simulation design.

References

Aşıksoy, G., & Islek, D. (2017). The impact of the virtual laboratory on students' attitude in a general physics laboratory. *International Journal of Online Engineering (iJOE), 13,* 20–28.

Avi, H., & Lunetta Vincent, N. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science Education, 88,* 28–54.

Bell, D. (2016). The reality of STEM education, design and technology teachers' perceptions: A phenomenographic study. *International Journal of Technology and Design Education, 26,* 61–79.

Bonde, M. T., Makransky, G., Wandall, J., Larsen, M. V., Morsing, M., Jarmer, H., et al. (2014). Improving biotech education through gamified laboratory simulations. *Nature Biotechnology, 32,* 694.

Brockmyer, J. H., Fox, C. M., Curtiss, K. A., McBroom, E., Burkhart, K. M., & Pidruzny, J. N. (2009). The development of the game engagement questionnaire: A measure of engagement in video game-playing. *Journal of Experimental Social Psychology, 45,* 624–634.

Broisin, J., Venant, R., & Vidal, P. (2017). Lab4CE: A remote laboratory for computer education. *International Journal of Artificial Intelligence in Education, 27,* 154–180.

Caprile, M., Palmén, R., Sanz, P., & Dente, G. (2015). *Encouraging STEM studies for the labour market*. European Union: Directorate General for Internal Policies.

Cavazza, M., & Young, R. M. (2017). Introduction to interactive storytelling. In R. Nakatsu, M. Rauterberg, & P. Ciancarini (Eds.), *Handbook of digital games and entertainment technologies* (pp. 377–392). Singapore: Springer.

Chang, V., & Guetl, C. (2010). Generation Y learning in the 21st century: Integration of virtual worlds and cloud computing services. In Z. W. Abas, I. Jung, & J. Luca (Eds.), *Proceedings of Global Learn 2010* (pp. 1888–1897). Penang, Malaysia: Association for the Advancement of Computing in Education (AACE).

Chen, X., Song, G., & Zhang, Y. (2010). Virtual and remote laboratory development: A review. In *Earth and Space 2010: Engineering, Science, Construction, and Operations in Challenging Environments* (pp. 3843–3852).

Choi, S., Jung, K., & Noh, S. D. (2015). Virtual reality applications in manufacturing industries: Past research, present findings, and future directions. *Concurrent Engineering, 23,* 40–63.

Coca, D. M., & Slisko, J. (2017). Software Socrative and smartphones as tools for implementation of basic processes of active physics learning in classroom: An initial feasibility study with prospective teachers. *European Journal of Physics Education, 4,* 17–24.

Corter, J. E., Nickerson, J. V., Esche, S. K., Chassapis, C., Im, S., & Ma, J. (2007). Constructing reality: A study of remote, hands-on, and simulated laboratories. *ACM Transactions on Computer-Human Interaction (TOCHI), 14,* 7.

Csikszentmihalyi, M. (2008). *Flow: The psychology of optimal experience* (1st ed.). Harper Perennial Modern Classics.

Csikszentmihalyi, M., & Csikszentmihalyi, I. S. (1992). *Optimal experience: Psychological studies of flow in consciousness.* Cambridge university press.

De Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science, 340,* 305–308.

Delaney, K., O'Keeffe, M., & Fragou, O. (2018). A design framework for interdisciplinary communities of practice towards STEM learning in 2nd level education. In M. E. Auer, D. Guralnick, & I. Simonics (Eds.), *Teaching and learning in a digital world* (pp. 739–750). Cham: Springer.

Dori, Y. J., & Belcher, J. (2005). How does technology-enabled active learning affect undergraduate students' understanding of electromagnetism concepts? *The Journal of the Learning Sciences, 14,* 243–279.

Dori, R. B., & Belcher, J. (2006). New physics teaching and assessment: Laboratory-and technology-enhanced active learning. *Handbook of College Science Teaching*, 97–106.

Dori, Y. J., Hult, E., Breslow, L., & Belcher, J. W. (2007). How much have they retained? Making unseen concepts seen in a freshman electromagnetism course at MIT. *Journal of Science Education and Technology, 16,* 299–323.

Foxlin, E., Harrington, M., & Pfeifer, G. (1998). Constellation: A wide-range wireless motion-tracking system for augmented reality and virtual set applications. In *Proceedings of the 25th Annual Conference on Computer Graphics and Interactive Techniques* (pp. 371–378).

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., et al. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences, 111,* 8410–8415.

Freina, L., & Ott, M. (2015). A literature review on immersive virtual reality in education: State of the art and perspectives. *eLearning & Software for Education*.

Garner, T. A. (2018). Applications of virtual reality. In *Echoes of other worlds: Sound in virtual reality* (pp. 299–362). Springer.

Gaspar, H., Morgado, L., Mamede, H., Manjón, B., & Gütl, C. (2018). Identifying immersive environments' most relevant research topics: An instrument to query researchers and practitioners. In *iLRN 2018 Montana. Workshop, Long and Short Paper, and Poster Proceedings from the Fourth Immersive Learning Research Network Conference* (pp. 48–71).

Górski, F., Buń, P., Wichniarek, R., Zawadzki, P., & Hamrol, A. (2017). Effective design of educational virtual reality applications for medicine using knowledge-engineering techniques. *Eurasia Journal of Mathematics, Science & Technology Education*, *13*.

Gütl, C., Scheucher, T., Bailey, P. H., Belcher, J., Santos, F. R., & Berger, S. (2012). Towards an immersive virtual environment for physics experiments supporting collaborative settings in higher education. In *Internet accessible remote laboratories: Scalable e-learning tools for engineering and science disciplines* (pp. 543–562). IGI Global.

Hamari, J., Shernoff, D. J., Rowe, E., Coller, B., Asbell-Clarke, J., & Edwards, T. (2016). Challenging games help students learn: An empirical study on engagement, flow and immersion in game-based learning. *Computers in Human Behavior, 54,* 170–179.

Harandi, S. R. (2015). Effects of e-learning on students' motivation. *Procedia—Social and Behavioral Sciences, 181,* 423–430.

HTC. (2018). *Vive User Guide*. Retrieved from http://dl4.htc.com/web_materials/Manual/Vive/Vive_User_Guide.pdf?_ga=2.82037588.318918390.1502103742-2091439008.1500636618.

Jabbar, A. I., & Felicia, P. (2015). Gameplay engagement and learning in game-based learning: A systematic review. *Review of Educational Research, 85,* 740–779.

Jimoyiannis, A., & Komis, V. (2001). Computer simulations in physics teaching and learning: A case study on students' understanding of trajectory motion. *Computers & Education, 36,* 183–204.

Kanematsu, H., & Barry, D. M. (2016). STEM and creativity. *STEM and ICT education in intelligent environments* (pp. 15–23). Cham: Springer.

Lindner, P., Miloff, A., Hamilton, W., Reuterskiöld, L., Andersson, G., Powers, M. B., et al. (2017). Creating state of the art, next-generation virtual reality exposure therapies for anxiety disorders using consumer hardware platforms: Design considerations and future directions. *Cognitive Behaviour Therapy, 46,* 404–420.

Lunce, L. M. (2006). Simulations: Bringing the benefits of situated learning to the traditional classroom. *Journal of Applied Educational Technology, 3,* 37–45.

Machet, T., Lowe, D., & Gütl, C. (2012). On the potential for using immersive virtual environments to support laboratory experiment contextualisation. *European Journal of Engineering Education, 37,* 527–540.

McCusker, J. R. (2018). *Is a Virtual Reality-based Laboratory Experience a Viable Alternative to the Real Thing?* Ph.D. dissertation, Wentworth Institute of Technology.

Molnar, A. (2018). The effect of interactive digital storytelling gamification on microbiology classroom interactions. In *2018 IEEE Integrated STEM Education Conference (ISEC)* (pp. 243–246).

Neumann, D. L., Moffitt, R. L., Thomas, P. R., Loveday, K., Watling, D. P., Lombard, C. L., et al. (2017). A systematic review of the application of interactive virtual reality to sport. *Virtual Reality*, 1–16.

Nir, O. A model for the development and implementation of field trips as an integral part of the science curriculum. *School Science and Mathematics*, *93*, 325–331.

Olmos, E., Cavalcanti, J. F., Soler, J.-L., Contero, M., & Alcañiz, M. (2018). Mobile virtual reality: A promising technology to change the way we learn and teach. In *Mobile and ubiquitous learning* (pp. 95–106). Springer.

Olson, S., & Riordan, D. G. (2012). Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. Report to the President. Executive Office of the President.

Pirker, J. (2013). *The Virtual TEAL World—An Interactive and Collaborative Virtual World Environment for Physics Education.* Ph.D. dissertation, Master's thesis, Graz University of Technology.

Pirker, J. (2017). *Immersive and Engaging Forms of Virtual Learning.* Ph.D. dissertation, Graz University of Technology.

Pirker, J., & Gütl, C. (2015). Educational gamified science simulations. In *Gamification in education and business* (pp. 253–275). Springer.

Pirker, J., Berger, S., Guetl, C., Belcher, J., & Bailey, P. H. (2012). Understanding physical concepts using an immersive virtual learning environment. In *Proceedings of the 2nd European Immersive Education Summit, Paris* (pp. 183–191).

Pirker, J., Gütl, C., Belcher, J. W., & Bailey, P. H. (2013). Design and evaluation of a learner-centric immersive virtual learning environment for physics education. In *Human factors in computing and informatics* (pp. 551–561). Springer.

Pirker, J., Holly, M. S., Hipp, P., König, C., Jeitler, D., & Gütl, C. (2017a). Improving physics education through different immersive and engaging laboratory setups. In *Interactive mobile communication, technologies and learning* (pp. 443–454).

Pirker, J., Lesjak, I., & Guetl, C. (2017b). Maroon VR: A room-scale physics laboratory experience. In *2017 IEEE 17th International Conference on Advanced Learning Technologies (ICALT)* (pp. 482–484).

Pirker, J., Lesjak, I., Parger, M., & Gütl, C. (2017c). An educational physics laboratory in mobile versus room scale virtual reality—A comparative study. In *Proceedings of the 14th International Conference on Remote Engineering and Virtual Instrumentation (REV), 2017. IEEE.* Springer.

Pirker, J., Lesjak, I., Parger, M., & Gütl, C. (2018). An educational physics laboratory in mobile versus room scale virtual reality—A comparative study. In *Online engineering & internet of things* (pp. 1029–1043). Springer.

Portman, M. E., Natapov, A., & Fisher-Gewirtzman, D. (2015). To go where no man has gone before: Virtual reality in architecture, landscape architecture and environmental planning. *Computers, Environment and Urban Systems, 54,* 376–384.

Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrović, V. M., et al. (2016). Virtual laboratories for education in science, technology, and engineering: A review. *Computers & Education, 95,* 309–327.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education, 93,* 223–231.

Pruett, C. (2015). *Squeezing Performance out of Your Unity Gear VR Game*. Retrieved from https://developer.oculus.com/blog/squeezing-performance-out-of-your-unity-gear-vr-game/.

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 & Gaming, 23,* 261–276.

Reeve, J., Jang, H., Carrell, D., Jeon, S., & Barch, J. (2004). Enhancing students' engagement by increasing teachers' autonomy support. *Motivation and Emotion, 28,* 147–169.

Sanders, M. E. (2008). STEM, Stem education, STEMmania.

Scheucher, B., Bailey, P. H., Gütl, C., & Harward, J. V. (2009). Collaborative virtual 3d environment for internet-accessible physics experiments. *International Journal of Online Engineering (iJOE), 5,* 65–71.

Settgast, V., Pirker, J., Lontschar, S., Maggale, S., & Gütl, C. (2016). Evaluating experiences in different virtual reality setups. In *International Conference on Entertainment Computing* (pp. 115–125).

Shurygin, V. Y., & Krasnova, L. A. (2016). Electronic learning courses as a means to activate students' independent work in studying physics. *International Journal of Environmental and Science Education, 11,* 1743–1751.

Slater, M. (2003). A note on presence terminology. *Presence Connect, 3,* 1–5.

Tüysüz, C. (2010). The effect of the virtual laboratory on students' achievement and attitude in chemistry. *International Online Journal of Educational Sciences*, *2*.

Tawfik, M., Salzmann, C., Gillet, D., Lowe, D., Saliah-Hassane, H., Sancristobal, E., et al. (2014). Laboratory as a service (LaaS): A novel paradigm for developing and implementing modular remote laboratories. *International Journal of Online Engineering (iJOE), 10,* 13–21.

Thompson, P. (2015). How digital native learners describe themselves. *Education and Information Technologies, 20,* 467–484.

Waite, A. J., Rosenberg, A., Frehm, V., Gravinese, P., Jackson, J., Killingsworth, S., et al. (2017). Using virtual reality to bring ocean science field experiences to the classroom and beyond. In *AGU Fall Meeting Abstracts.*

Wieman, C., & Perkins, K. (2005). Transforming physics education. *Physics Today, 58,* 36.

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence, 7,* 225–240.

Zeidler, D. L. (2016). STEM education: A deficit framework for the twenty first century? A sociocultural socioscientific response. *Cultural Studies of Science Education, 11,* 11–26.

Chapter 12
Designing Learning Activities Using Different Augmented Reality Applications for Different Learning Subjects for Elementary Students

Sie Wai Chew and Nian-Sing Chen

1 Introduction

The advancements in science and technology in recent decades had provided limitless avenues for developments across all fields and industries, including the field of education. These emerging technologies are receiving much attention and reaching high popularity among users and developers, which promoted educators to participate in the action. Introducing new technologies into classrooms has been an ongoing movement, with numerous research efforts invested in them to explore their effectiveness in improving the learning and teaching process for both students and teachers. These new technologies (or techniques) include interactive tables, motion sensing interactive system, virtual reality, augmented reality, mixed reality and more (Chew, Cheng, Kinshuk, & Chen, 2018; Kinshuk, Chen, Cheng, & Chew, 2016). This chapter focuses on the augmented reality technology and shared about its potential in the usage of different learning subjects taught in schools, particularly for elementary schools.

The usage of augmented reality technology alone is not enough to improve the learning experience in classroom, past research complimented the usage of the technology along with different learning pedagogies, including situated learning, inquiry-based learning and game-based learning (Chiang, Yang, & Hwang, 2014; Hwang, Wu, Chen, & Tu, 2016). These research had shown that by combining augmented reality technology with different learning pedagogies not only improve the students' learning performance and deepen their understanding, students were also immersed

---

S. W. Chew
Department of Information Management, National Sun Yat-Sen University, Kaohsiung, Taiwan
e-mail: chewsw@mis.nsysu.edu.tw

N.-S. Chen (✉)
Department of Applied Foreign Languages, National Yunlin University of Science and Technology, Douliu, Taiwan
e-mail: nianshing@gmail.com

P. Díaz et al. (eds.), *Learning in a Digital World*, Smart Computing and Intelligence, https://doi.org/10.1007/978-981-13-8265-9_12

in the learning process, making student more eager to learn and motivate them to seek for more information in regards of the learning topic (Bacca, Baldiris, Fabregat, Graf, & Kinshuk, 2014; Martín-Gutiérrez, Fabiani, Benesova, Meneses, & Mora, 2015; Santos, Taketomi, Yamamoto, Rodrigo, Sandor, & Kato, 2016).

There are numerous augmented reality software and applications available in the market for teachers and educators to utilize and introduce the technology into the classroom. Most of these augmented reality software and applications require users to be equipped with some programming skills to allow users to design and make customization in accordance with their requirements and needs. Hence, even though teachers and educators are well aware with the augmented reality technology and its benefit for improving the learning process, with the lack of programming skills, teachers and educators find augmented reality technology difficult to be customized to accustom to their teaching requirements and needs. On contrary, there are alternative augmented reality software that teachers and educators could utilize without much programming skills required, such as Blippar, Layar and Aurasma. These augmented reality applications are well known to be easy to use and customizable with a drag-and-drop mechanism which enables users with no programming background to participate in the augmented reality action. These different augmented reality software and applications have their advantages and disadvantages in the classroom, especially in terms of the customizability and flexibility teachers and educators are provided within changing the learning topics and materials on these software and applications. The research objective of this chapter to identify and discuss key items/factors for teachers and educators in selecting from a various selection of augmented reality applications in designing learning activities for different learning subjects for elementary school students. The research question of this chapter is “For teachers and educators, what are the key items/factors in play in the process of selecting from different augmented reality applications in designing learning activities for different learning subjects for elementary school students?”

This chapter discusses the two research that utilized different augmented reality software in developing its applications, along with the usage of different pedagogies and strategies for different learning subjects to improve the learning experience and performance among elementary school students. One of the research utilized Unity and Vuforia in the subject of science, requiring proficiency in programming skills which enables high level of customization with rich media and features in the application. Another research utilized a readily available online platform, Blippar, in designing the augmented reality application for the subject of history and culture which is easy and simple to use for teachers and educators. A discussion on the benefits and shortcoming of the different pedagogies and the two different applications used in the two research are discussed.

2 Learning Pedagogy and Strategy

Instead of buying a fairly expensive machine in the makerspace, we got hold of someone who actually knew about the new machine. The local makerspace had lots of experts, and they were happy to share their knowledge. Hence, we can conclude the three main practices we defined from the makerspace, there are sharing, creating and participating. Generally, in the makerspace, we all focus on the sharing, but perhaps we are lacking the last two. Besides, the budget of maintaining makerspace is limited, makers have not so many chances to practice their idea for real and let alone the remote places have no money to maintain the makerspace.

2.1 *Collaborative Learning*

As the capability to work with diverse group of people has become a crucial skill in the globalized economy and market, collaborative learning has emerged as one of the essential twenty-first-century skills that students should master in order to succeed in their career (Kay & Greenhill, 2011; Mishra & Kereluik, 2011). Collaborative learning requires students to work in small groups, "mutually searching for understanding, solutions, or meanings, or creating a product" (Smith & MacGregor, 1992, p. 11). Collaborative learning has shifted the education spectrum from teacher-centred to student-centred, enabling students to explore the learning topics together, delegating tasks among the group, knowledge sharing and conducting discussions to enhance the understanding of the group members (Dillenbourg, 1999; Smith & MacGregor, 1992). The value of collaborating with peers is best instilled at a young age (Brown & Warschauer, 2006). In schools, especially in elementary schools, classroom settings are mainly designed for individual learning. Collaborative learning is used in recent research to promote the value of collaborating with peers and also to enhance students' learning enthusiasm and engagement (Sung & Hwang, 2013).

Collaborative learning is an active, constructive process that is enriched with challenging tasks in order to engage students in completing the learning task together (Smith & MacGregor, 1992; Sung, & Hwang, 2013). With diversified group members, this would enable students with different knowledge backgrounds to share and discuss their thoughts for the betterment of the group. Collaborative learning provides students opportunity to share their thoughts and understanding, and also to learn to listen to others' opinions and to acknowledge their perspectives (Smith & MacGregor, 1992). There are five basic elements of collaborative learning, namely, (1) positive interdependence; (2) individual and group accountability and responsibility; (3) interpersonal and small group skills; (4) face-to-face interaction; and (5) group processing (ITS Training Services, 2014; Laal, 2013), as shown in Table 1.

Past studies had shown that collaborative learning has positive impact on the learning performance (Sung & Hwang, 2013; van Dijk, Gijlers, & Weinberger, 2014). For example, in Brown's (2008) and Capdeferro and Romero's (2012) research, a ques-

Table 1 Basic elements of collaborative learning and their definition (ITS Training Services, 2014; Laal, 2013)

Basic elements of collaborative learning	Definition
Positive interdependence	Each group member believes that everyone's effort in completing the task or goal is essential and the success of the group is linked to the performance of each group member
Individual and group accountability and responsibility	Each group member is accountable for doing their part in order for all to work towards completing the group' task
Interpersonal and small group skills	Each group member is encouraged to appreciate each member, develop leadership, build trust, play a role in decision-making, communicating and managing conflicts among the group members
Face-to-face interaction	Each group member helps and encourages one another to learn by sharing their understanding and gathering everyone's input
Group processing	Each group member communicates openly to express their concerns and maintains effective working relationships

tionnaire was used to review students' perceptions on collaborative learning and to determine whether they find collaborative learning beneficial to their learning process. It was found that students acknowledged that collaborative learning benefits their academic performance, social and generic skills. Similar results have been found for elementary students, with most research focusing on game-based learning and online computer-supported collaborative learning (CSCL) (Capdeferro & Romero, 2012; Sung & Hwang, 2013; van Dijk, Gijlers, & Weinberger, 2014). It was found that few research in collaborative learning have focused on exploring the actual scenarios and situations that occur in the classroom during a collaborative learning setting, especially for elementary school students. The research of Study 1 designed an augmented reality application to facilitate elementary school students learn about scientific topics (i.e., the source of energy, transfer of energy and force, and electric circuits) which enables students to collaborate with their peers to complete the designed learning activities.

2.2 *Inquiry-Based Learning*

The process of learning the subject of science comprises of the skills in identifying and solving problems, formulating hypothesis, designing and conducting experiments, interpreting and analysing data (Engeln, Mikelskis-Seifert, & Euler, 2014; Hwang, Chiu, & Chen, 2015; Lazonder & Harmsen, 2016; Tamir, 1990). In contrast, the teaching practice of elementary science favours to concentrate on the scientific processes, following certain procedure in conducting observations, constructing hypothesize and conducting experiments (Ann Haefner & Zembal-Saul, 2004). However, this practice supports students very little, if any, to engage in problem-solving, reasoning and critical thinking (Ann Haefner & Zembal-Saul, 2004; Roussou, 2004). Past research has suggested that in order to gain knowledge of science effectively, the scientific concepts should be taught in the existing nature of the scientific knowledge (Chen, Wang, Lu, Lin, & Hong, 2016; Hsu, Chang, Fang, & Wu, 2015; Tamir, 1990).

As defined by Engeln et al. (2014), inquiry-based learning involves teachers conducting the learning process via teaching as inquiry, especially for the subject of science. Inquiry-based learning allows students to investigate scientific concepts first hand by "constructing their own knowledge by testing ideas and concepts based on prior knowledge and experience, applying them to a new situation, and integrating the new knowledge with pre-existing intellectual constructs; a process familiar to us from real world situations" (Roussou, 2004, p. 4). By doing so, students will learn and understand these science concepts, and more importantly, they would acquire new scientific knowledge and internalize these concepts (Ann Haefner & Zembal-Saul, 2004). For elementary students, learning by doing or hands-on activities which "emphasized that children should be engaged in activities where there is a physical or 'hands-on' manipulation of objects" (Ann Haefner & Zembal-Saul, 2004, pp. 1663), would be appropriate as they provide students opportunity to venture and test their ideas, make necessary amendments and participate in the problem-solving process (Roussou, 2004). With past research indicating that collaborative learning would enhance students' academic performance, social and generic skills along with the benefit of inquiry-based learning in learning science, Study 1 focused on improving the learning process and enhance the learning performance of students in elementary science using both collaborative learning and inquiry-based learning. In order to examine this, Study 1 designed an augmented reality application to assist students in learning elementary science via collaborative learning, using the strategy of inquiry-based learning to further improve the learning experience and learning performance of elementary school students.

2.3 Situated Learning

By experiencing the occurrence of events at its authentic location and learning regarding a topic in its actual environment, through situated learning, students could understand the scenario better, which would result in students coming up with better solutions in solving which occurs in the environment itself (Dawley & Dede, 2014). Chu, Hwang, Tsai, and Tseng (2010) had mentioned the role of situated learning in enhancing the learning process and deepening students' understanding of the problem when students are placed at the authentic settings of the problem. Situated learning provides students a better view of the whole scenario, and the opportunity to experience and understand the importance of solving these problems when situated in the environment themselves. This is especially evident in learning about culture and understanding about history where one would be able to experience the cultural activity firsthand instead of reading it on texts, and understand about the history of a town by witnessing the landmarks and sites in person.

The subject of culture and history is important in cultivating students' appreciation in their own culture and interest in history. These values should be cultivated among students starting at a young age. In order to enrich the learning content of the subject of culture and history, technology is used to improve students' learning experience of the subject which students often finds them boring and dull. Thus, in Study 2, the research utilized the situated learning strategy in designing an augmented reality application for elementary school students to learn about the local history and culture.

2.4 Augmented Reality (AR)

Augmented reality (AR) is a technology that can provide users with virtual objects which are based on the real world (Azuma, 1997; Chiang et al., 2014). Many research works have shown that learning using augmented reality could enhance students' learning performance by improving the learning process, making the learning process more immersive and increasing students' motivation and engagement (Hwang et al., 2016; Lu & Liu, 2015). In addition, recent research has found that augmented reality approaches can play a significant role during the learning process, with its potential to improve students' engagement, and enhance their interest and understanding regarding the subject, augmented reality technology has the ability to portray concepts and ideas more clearly to students to deepen students' understanding of the learning topic (Hwang et al., 2016; Lu & Liu, 2015). Students learning through augmented reality are assisted by virtual objects and information that is overlaid on the actual environment, and students can interact with the virtual objects and information using their senses (i.e. touch, sight and sound). Augmented reality technology, therefore, provides students with firsthand knowledge from the actual environment with the aid of virtual items by creating an authentic learning environment (Azuma, 1997; Chiang et al., 2014).

In the current market, Unity and Vuforia are among the few software which are popular among developers in designing augmented reality applications. These software enable developers to customize the augmented objects according to their requirement in a three-dimensional space, which would result in fantastic display of these items when they overlay with the real-world environment. For the best presentation of the augmented objects with the designated environment, much programming skills are required to ensure the perfection of every detail. This had been one of the main reasons teachers and educators could not involve themselves with the designing and usage of the technology. There are other augmented reality software and platforms available for easy design and customization, such as Blippar and Layar. These software have readily available application for devices running on iOS and Android, making it applicable to most device. These software provide platform where the teachers and educators could upload their materials and make minimal customizations. Most of these platforms use a drag-and-drop mechanism, making it easier for users who are not familiar with the coding process of the program. For the two research discussed in this chapter, one research had utilized Vuforia which had enabled a personalized design of the learning application that had required professional programming skills; the other research had utilized Blippar in designing its learning application for easy customization with less flexibility in terms of application features and functions.

3 Research Study

In designing a learning activity for students, during a collaboration between researchers and elementary schoolteachers, the importance of the teachers having a clear idea on the whole learning activity and the way they hope the designed learning activity was presented to the students was prominent. This includes the type of learning activities, the expected interaction of the students during the learning activity, the learning contents and assessments. Thereafter, the researchers could assist in introducing the available technology and application suitable for the learning activity and learning settings. The two research were presented utilizing different augmented reality applications to assist students in learning about topics in science and cultural study, respectively.

3.1 Study 1: Science

In Chew, Lin, Huang, Kinshuk, and Chen's (2017a) study, augmented reality technology was utilized along with inquiry-based learning in the subject of science for elementary school students. An augmented reality (AR) application, ScienMon, was designed in the study, which operated on Android tablets, designed from scratch using the software Unity and Vuforia. The augmented reality technology played the role of providing students with their learning tasks, creating and engaging learning environment for students, and also to assist in checking the group's answers and verify the completion of the group's hands-on activity.

After the discussion with the elementary schoolteachers, the learning topic of this study consisted of the source of energy, transfer of energy and force, and electric circuits. With the objective of providing students an opportunity to learn about different cultures and learn to work together as a group while learning about these scientific topics, the designed application consisted of six sets of questions and tasks on the aboriginal culture and the scientific topics. During the learning process, students were required to discuss these topics together, collaborate in completing all the designed hands-on activities and questions, in order to retrieve their final mission (i.e., building a solar energy car on their own). In order to build this solar energy car from scratch, students had to understand the difference in parallel and series circuit, the positive and negative poles, the importance of a solar panel, and the concept of the transfer of energy in a gear wheel and gear belt.

3.1.1 Activity Design

The application, ScienMon, was built using the software Unity and Vuforia, and operated on Android operating systems. The study design required each group to be equipped with a tablet with the application installed, along with a box of items that were required for the completion of various hands-on activities (including galvanometer, solar boards, wires, cardboards, wheels, wheel axle, scissors, motor, buzzer, a set of gear wheels and gear belts). Six learning activities were designed in the application where each learning activity consisted of an aboriginal culture question and a scientific activity. Six colour pieces were displayed at the initial interface of the application. Students were required to complete each learning activity in order to reveal parts of the image behind each colour piece to finally retrieve the final assignment, which was to build a solar car (as shown in Fig. 1).

Aboriginal cultural questions were introduced in the application as the study took place at a unique aboriginal school, where the local tribe had decorated the school with items of their rich culture. These questions were designed to initiated students' interest in different cultures, and cultivate their appreciation and respect to different cultures. The designed aboriginal cultural questions required students to explore the school to find information in regard to the aboriginal culture to assist them in

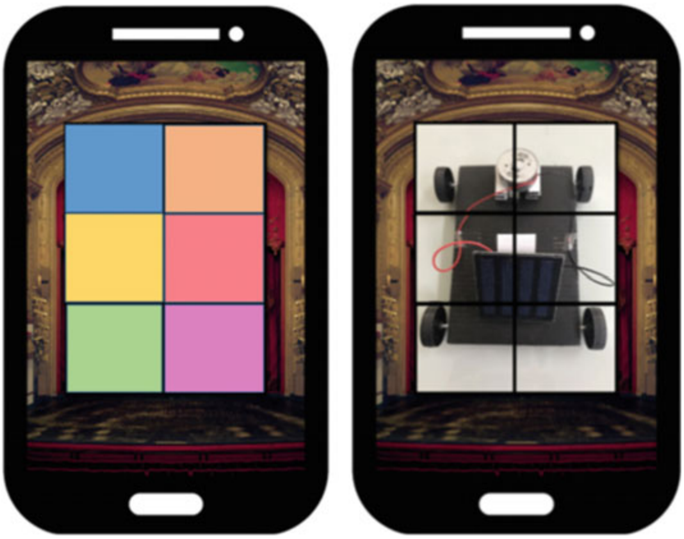


Fig. 1 Initial interface of the application and the final assignment

[redacted]國小學區內主要以什麼原住民族群為主？

A. 賽夏與排灣族

B. 布農與鄒族

**提供相關AR物件的資訊

Fig. 2 Aboriginal cultural question interface

answering the questions. Once they had answered the question correctly, in order to ensure that they had indeed visited the intended location in the school, students were required to use the augmented reality technology to scan and verify the item or object referred to in the questions. This is an example where the augmented reality technology was used to verify the location of students by introducing the landmark scanning activity. As an example of the aboriginal cultural question, as shown in Fig. 2, the students were required to figure out the main tribe of the students of this school. The questions for the aboriginal cultural questions were all multiple-choice questions where students were allowed to answer the questions multiple times. Thereafter, the application would provide students with a blurred out image of the targeted landmark along with some additional information in regard to the question asked. In order to verify that students had found the landmark, students utilized the scanning mode in the application to scan the targeted landmark.

Besides learning about the aboriginal culture of the school, ScienMon was mainly designed as a platform that provided students the opportunity to collaborate with members of their group while learning about source of energy, transfer of energy and force, and electric circuits. Instead of having a teacher teaching students about these scientific topics, this learning activity allowed students to experiment and learn about these topics by actual experimentation. As students were working as a group, group members who figured out the question or topic shared their understanding with other members of the group. These learning topics were crucial in enabling each student to complete their final task, which was building a solar energy car. In order to build this solar energy car from scratch, students had to understand the difference in parallel and series circuit, the positive and negative poles, the importance of a solar panel, and the concept of the transfer of energy in a gear wheel and gear belt. Hence, these scientific activities were designed accordingly with the advisement from the elementary schoolteachers to ensure that with the hands-on activity installed for the group, students were able to understand and learn about these scientific topics.

After completing one aboriginal cultural question and activity, students were then required to complete a scientific question and activity to complete one set of learning activity. The learning activities designed in the application consisted of different types of questions and activities, including open-ended questions, fill in the blanks and completion of hands-on activity. Each group of students was given a box of items that were required for the completion of various hands-on activities (including galvanometer, solar boards, wires, cardboards, wheels, wheel axle, scissors, motor, buzzer, a set of gear wheels and gear belts). Students were required to complete the hands-on activity designed for each of these questions in order to retrieve the answer. For the scientific questions, students were only given one attempt to answer the questions; hence, they had to be confident with their answers before submitting them to the application. This was to encourage students to discuss among group member to ensure that the answer was final and accurate before submitting their answer and to prevent students from "testing" their answers by try and error.

As an example of the scientific question, as shown in Fig. 3, "What is a parallel circuit?" each group was required to use items provided to build a parallel circuit (i.e., galvanometer, solar panels and wires). Students provided with the equipment and tool required for them to try building a parallel circuit compare and witness firsthand the difference of both parallel and series circuits. Students were allowed to attempt building the circuit as many times as they require and they could even venture into experimenting the circuit with different components. As a group, students were allowed to discuss and share their observation and thoughts among the group to better assist the group to learn about the learning topic together. After completing the hands-on activity, the groups were required to verify the work using the tablet's camera to scan their work. As all the parts of the items provided were marked, the application used the technology of augmented reality to identify each component using the markers and ensure that the poles were connected in accordance with the questions. This enabled the application to verify the group's work and provide them with their result instantaneously by identifying whether the positive pole of the solar panel was connected to the positive pole of another solar panel to build a parallel circuit. For the scientific question, each group was given one attempt for each question. If they were unable to answer the question correctly, the group would lose that part of the puzzle where they were not allowed to attempt the question again.

Another example of the hands-on activity covers the topic of the transfer of energy and force, where students utilized the gear wheels and gear belts provided, to design different arrangement sets of the gear wheels spinning in the same directions and in opposite directions. Students were required to build the setup of the gear wheel and belt, and their end results would be verified by the application using the augmented reality technology. With the completion of the scientific question, students would move on to the next set of learning activity in order to reveal the other parts of their final assignment until all six learning activities were completed (see Fig. 4).

After completing all six learning activities, students were required to complete the final assignment, building a solar car (as shown in Fig. 1). For the final assignment, students were required to use the knowledge they learnt (i.e. difference in parallel and series circuit, methods to use solar power, transfer of energy and force through gears) to build a solar car individually with the materials provided (i.e. solar boards, wires, cardboards, wheels, wheel axle, scissors, motor). Total duration of the study

Fig. 3 Scientific question interface

Fig. 4 Study's learning process

was five hours as the learning process involved students exploring around the school area, trying out different hands-on activities and building the solar car (Fig. 5).

3.1.2 Evaluation Tool

The participants of this research were students from two elementary schools (Grade 4 to Grade 6) in Kaohsiung, Taiwan, with a total of 39 participants. Elementary students of Grade 4 to Grade 6 were selected for this research as they would had learnt about the learning topics designed in this research in class (i.e. source of energy, transfer of energy and force, and electric circuits). After the study, the students completed a questionnaire on collaborative learning to assist in evaluating the students' learning process and learning experience. The questionnaire consisted of 20 questions, each with a 7-item Likert scale (Brown, 2008; Capdeferro & Romero, 2012, questions

Fig. 5 Students solving the questions by completing hands-on activity to retrieve the answer

Table 2 List of questions in the questionnaire on collaborative learning

Questions			
1	Helped understanding/comprehension	11	Enhanced communication skills
2	Fostered exchange of knowledge, information and experience	12	Improved performance
3	Made problem-solving easier	13	Students actively participated in the teaching/learning process
4	Stimulated critical thinking	14	It was fun
5	More relaxed atmosphere	15	Made new friends
6	Received useful/helpful feedback	16	Fostered team spirit
7	Got fresh insight	17	Waste of time explaining things to others
8	Focused on collective efforts rather than individual effort	18	Difficult getting members to actively participate in tasks
9	Greater responsibility—for myself and the group	19	(Pair/group work) should be encouraged/continued
10	Enabled students to help weaker students in the group	20	Maximum group size should be four

Note Questions from Brown (2008), and Capdeferro and Romero (2012)

see Table 2). As Brown (2008) mentioned, this questionnaire was designed to provide students' perception on collaborative learning, understand whether they find collaborative learning useful and identify items that could be improved for future collaborative learning sessions. Among the students of each group, one student was chosen at random from each group to complete a brief interview session in order to understand further the impact of the research on the students (nine interview questions, see Table 3).

Table 3 Questions asked during the interview session

Interview questions	
How many were you in a group when you were engaged in this activity?	What role do you think the teachers should play in preparing students for this activity?
What were the academic benefits?	How did your group deal with problem or problem member?
What were the social benefits?	Do you feel that you learned more as part of a group than you would have working on the assignment individually?
How were "roles" assigned or did group members had equal status?	Is there anything you would change about your behaviour or approach in future collaborative learning situations or inquiry-based learning situations?
What worked well and what didn't?	

Note Questions retrieved from Brown (2008), and Capdeferro and Romero (2012)

3.1.3 Evaluation Findings

The evaluation findings of the collaborative learning questionnaire had shown promising results including "Academic benefits", "Social benefits", "Generic/Life-long learning skills" and "Negative aspects of collaborative learning" (Brown, 2008). As for the questionnaire on collaborative learning that consisted of 20 questions, the feedback results of the students were grouped into three groups for analysis (viz. 7-item Likert scale output grouping: Positive = 5, 6, 7; Neutral = 4; and Negative = 1, 2, 3). The results showed that most students had the opinion that collaborative learning had positive effect on their academic benefits (with positive feedback of 89.74%, see Table 4, $N = 35$). This included helping them to understand the topic, knowledge and experience sharing, and receiving insightful feedbacks from others. In addition, most students were of the opinion that collaborative learning would have positive effect on their social skills (with positive feedback of 91.45%, $N = 36$), including the fact that working together was fun, it allowed them to make new friends and it provided the feeling of learning taking place in a more relaxed environment. In terms of life-long learning skills (i.e. problem-solving, critical thinking, collective effort and team spirit), 91.03% of the students had positive feedback on the benefits of collaborative learning (i.e. $N = 36$). For negative aspects of collaborative learning (i.e. waste of time explaining things to others, and difficulty in getting group members to participate), 74.36% (i.e. $N = 29$) of the students did not agree with these statements. However, there were 19.23% ($N = 8$) of students who had neutral opinions regarding these statements and 6.41% ($N = 3$) of students who agreed with these statements.

Besides collecting feedback from students through the questionnaire on collaborative learning, an interview session was also conducted in order to further understand the students' experiences and their opinions on collaborative learning. A qualitative content analysis was conducted on the results of the interviews, as shown in Table 5. One member from each of the 10 groups was selected at random to participate in the interview session, with five students from each school. The questions asked during

Table 4 Results from the questionnaire on collaborative learning

Category[a]	Negative (%)	Neutral (%)	Positive (%)
Academic benefits	3.66	6.59	89.74
Social benefits	1.71	6.84	91.45
Generic/Life-long learning skills	1.28	7.69	91.03
Negative aspects of collaborative learning	74.36	19.23	6.41

Note [a]Category grouping with reference to Brown (2008). 7-Likert scale output grouping: Positive = 5, 6, 7; Neutral = 4; and Negative = 1, 2, 3

Table 5 Collective results from the personal interview session

Basic elements of collaborative learning	Feedback
Positive interdependence	• More confident as I know if I don't know the solution to the question, I could ask for help from group members • When others understood the topic, I would push myself to ask questions to make myself understand the topic too • Working as a group makes completing the tasks easier
Individual and group accountability and responsibility	• Delegating tasks among group members • Task assigned in accordance with member's ability
Interpersonal and small group skills	• Take turns to play certain role • Learn from other's experience
Face-to-face interaction	• Help other members to understand the task • Listen to the opinion of others • Enjoyed team spirit
Group processing	• When faced with a problem, we would discuss and think of a solution together • Share our opinion with the group

Note With reference to ITS Training Services (2014) and Laal (2013)

the interview session, as shown in Table 3, were adopted from Brown (2008) and Capdeferro and Romero (2012).

Results of the interviews identified that for most groups, not every member of the group participated actively in the learning process (students reported that only four groups had full participation from all members). Usually, there were one or two members of the group who were more active and led the group to complete each task. In terms of assigning roles among group members, interviews indicated that most of the group members took turns in playing different roles in completing the tasks (i.e. handling the tablet for task assignments, solving questions and tasks, leading the group to the next location in the school, ensuring the usage of items for hands-on activities), and designated tasks were delegated to group members according to their own ability and willingness to hold certain responsibility. Interviewees shared that there were some groups where no particular assignment of roles was done as each member completed their task equally.

In terms of academic benefits, most of the students shared that they enjoyed the learning process as it required them to complete hands-on tasks. They mentioned that it was easier and more interesting for them to understand the concepts of electric circuits and movements of gears through hands-on activity and by having discussions with the assistance of other group members. Students also mentioned that by working with others, when they realize that other group members understood the topic well, it encouraged them to put in more effort to understand those topics in which they fell behind. Collaborative learning and inquiry-based learning provided a platform for the students to learn from peers; hence, students felt more relaxed and comfortable in asking their peers for assistance when they did not understand the question or topic, in comparison to asking their teachers. As the students were from different grade levels (Grade 4 till Grade 6), it provided the opportunity for the students from a higher grade to share their knowledge and experience with other students. This not only provided an opportunity for students to learn from peers but also to enhance their own understanding of the topic as they would have to articulate their thoughts to be able to explain the topic to others.

In terms of social benefits, this research created an atmosphere of diversified groups as students from different schools and different grades formed these groups together. Most of the students shared that collaborative learning enabled them to make new friends and gave them the opportunity to share their experience and thoughts with one another (since some students were from city while others were from the rural area). When faced with problems or issues, students reported that they sought opinions of all group members and accumulated every opinion into the decision-making process. They learnt to listen to other's opinions and respect their perspectives and views on the problem.

In terms of teacher's role during the collaborative learning activity, it was noticed that some students preferred for the teachers to conduct a teaching session on the topic before starting their assignments. As for this research, it was designed that the only learning content delivered by the researchers and teachers in a lecture mode in the classroom was to explain the research process, the function of the application and the importance of the materials provided to each team. Besides, students suggested that teachers should play an active role in assisting students when they were faced with any problems in understanding the learning materials, and provide students with directions and hints to move forward.

Finally, the students commented that in future collaborative learning opportunity, they would like to improve their learning experience by joining the group with an open attitude and a better behaviour (i.e. learning to be a team player). They shared that they would be more committed in group discussions and they would learn to master the skill of listening to others' opinions. Some students mentioned that they were too shy to contribute to the group and they felt that they could contribute more to the group if they could overcome their fear of speech. A collection of the students' feedback during the interview is shown in Table 5 in terms of basic elements of collaborative learning (ITS Training Services, 2014; Laal, 2013).

3.2 Study 2: Cultural Study

For this study, the elementary schoolteachers hoped to improve their school's annual field trip for the students. Every year, a field trip was organized by the school to enrich students with the exposure to the local culture and history, and to instil interest and appreciation among students on the importance of the cultural preservation. In order to identify key elements in improving the learning experience of students during the field trip, Chew, Lin, Huang, and Chen's (2017b) study compared the utilization of augmented reality technology for a classroom setting learning and an outdoor field trip learning in the subject of cultural study for elementary school students. This study involved comparing having students learning about the cultural and historical topic about Tainan city in their classroom, and students learning about the cultural and historical topics about Qishan while visiting the town. The application was used to facilitate students in learning about the culture and history of both Tainan city and Qishan town. The augmented reality application used in this study was Blippar, which is an application that operates on iOS and Android systems. The application has an easy to use platform where users could upload materials they want to present in the application on the platform, and easily drag and drop for customization. For this study, augmented reality technology played the role of location verification and information presentation.

This study consisted of two parts, a classroom setting and an outdoor field trip setting. Both settings utilized the augmented reality application Blippar to deliver information about Tainan city (for classroom setting) and Qishan town (for outdoor field trip setting). Both settings each consisted of four learning topics where for each learning topic its relevant information was included in the "Tour" mechanism, and the assessment of each learning topic was inserted in the "Quiz" mechanism. For the "Tour" mechanism, images and information of each topic were shared, along with a short video introducing further regarding the topic. There were a total of 27 elementary school students who participated in the study, ranging from Grade 3 till Grade 6.

3.2.1 Classroom Setting Activity Design

For the study of the classroom setting, the topic scope was regarding the historic landmark and culture in Tainan city. The elementary schoolteachers assisted in deciding the learning topics for this study to ensure that there was a balance in between the historical elements and the cultural elements in the learning topics.

Thereafter, the relevant information of each learning topic were collected, including the images used in Blippar, the information portrayed in Blippar and the selection of suitable short videos of the learning topic. The information were prepared as images along with its relevant pictures to enrich the students' learning experience as shown on the left of Fig. 6. All the items were uploaded to the Blippbuilder platform of the Blippar application to begin the customization and design of the augmented

Fig. 6 Blippbuilder in the Blippar platform for classroom setting

reality learning activities. With all the items readily available on the Blippbuilder platform, the relevant items were then dragged and dropped to the customization area of the platform to begin building the interface of the learning activity (as shown in Fig. 6). The Blippbuilder platform allowed a customization on the actions after an item was tapped by the user, including moving to the next scene (similar with moving to the next page), playing an audio or video file and opening a website.

For the classroom setting, each student was provided with an Android tablet and a pair of headsets, with the learning duration of 40 min (as shown in Fig. 7). As this study was conducted in the classroom setting, the markers of each learning activity (trigger for the augmented reality learning activity) were printed on a learning sheet where each student had a copy (as shown in Fig. 8). After students scanned a marker on the learning sheet, the application began from the main scene where the interface portrayed the name of the topic, the image of the landmark or item, and two active items on the bottom, which was the "Tour" and "Quiz" mechanism of each learning topic (as shown in Fig. 6). By tapping on the "Tour" item, the application began with the prepared learning materials, each portrays one after another with the students tapping on the next button. The "Tour" mechanism for each learning topic ended with the short video before returning back to the main scene. With the completion of the learning activity, students continued on with the "Quiz".

After completing the "Quiz" of the learning topic, students continued on with the other learning topics using Blippar to scan another marker till all four learning topics

Fig. 7 Students using the application in a classroom setting

Fig. 8 Learning sheet for the classroom setting

were completed. With the completion of the learning topics, students were required to complete a questionnaire to provide their feedback on their learning experience and suggest improvements that might better improve their learning experience. Some of the feedbacks received are as shown in Table 6.

3.2.2 Outdoor Field Trip Setting Activity Design

For the outdoor field trip setting, the strategy of situated learning was included in designing the learning activity. The topic scope of this study was regarding the historic landmark and culture in Qishan town. The students were brought to Qishan town in person to visit the historic landmark and experience the local culture. There were four learning topics designed for this study, including “Youth Banana”, “Qishan train station”, “Banana cake” and “Traditional Chinese seal”. These were historical landmarks and local delicacies which were well known in Qishan town.

Table 6 Result of the feedback questionnaire of the classroom setting (adopted from Chew et al., 2017b)

What improvement could be done by this application in order to make it more enjoyable?	
• The questions could be more challenging • Increase the number of learning topics • More information and further explanation could be provided • Pictures could be included in the question section	• Learning could take place outdoor • Enrich the learning materials to make it more interesting • Separate the learning information and videos • Games could be included • Interaction or feedback could be provided
In your opinion, what are the benefits of learning with this application?	
• Learn and understand more about Tainan's history and folk culture • Enjoyed that it allowed me to think of the answers instead of providing information for me to look for the answers • Different from what we learn in class and it shared some interesting facts that I hope to understand further	• Interesting and simple method of learning history and culture as I don't have to memorize and easy to remember • I don't need to go outdoors and I could see the landmarks and actual food comfortably in the classroom

In accordance with the questionnaire feedback received from the classroom setting study, improvements were made on the application design of the outdoor field trip setting. As mentioned in Chew et al. (2017a, b), with the feedback received from the students during the classroom setting activity, several amendments were made to the content of the learning activity and the layout of the augmented reality application Blippar as listed below:

- **The layout of the main scene**

Similar to the classroom setting, the outdoor field trip setting utilized the augment reality application Blippar to portray the learning activities to students. After students scanned the marker on site, the application entered the main scene of the learning activity. According to the feedback received from students, they found that with all the information bundled in the "Tour" mechanism, the application was rather inconvenient as students were not given the freedom to select topics which they might need a second look on. For example, students mentioned that during the classroom setting, the short video was located at the end of the "Tour" mechanism. For students to rewatch the video again, they had to go through all the learning materials which were placed before the video just to watch the video again. Hence, the layout of the main scenes of the learning activities after students scanned the marker with the application was amended to enable students to select from different topics of the learning activity. The image used in main scene was broken into different parts to enable for different functions for each part of the image. For example, for the learning topic on "Qishan train station", an image of the train station was used in the main scene. This image was broken into three part as shown in Fig. 9 where one part of the image was on the "Unique construction structure of the train station". For this part, once the image was tapped, the application entered the scene of introducing the

Fig. 9 Blippbuilder in the Blippar platform for outdoor field trip setting

unique construction structure of the train station where information were portrayed with images, and students had to tap on the next button to move on to the next scene. Other parts of the image consist of "The history of the train station" and "The Sugar Train line" which consist of the short video of the learning topic.

- **Including students' effort in designing the items of the study**

In the designing process of the interface of the augmented reality application Blippar and the materials of the learning activities of the classroom setting, all materials were prepared by the researchers and the elementary schoolteachers. Students shared that they enjoyed using the application in learning about the history and culture of Tainan city. With all the positive feedback received, students did share that they did not feel like the learning activity and the design of the application was unique or specifically for them. Hence, in the process of designing and preparing the learning activities of the outdoor field trip setting, students participated in the process by contribution their hand-drawn artwork of the landmarks and cultural items. As shown on the left of Fig. 10, students' artwork was included in the main scene of each learning activity to improve the sense of ownership and contribution among students. As for students who did not contribute, with these hand-drawn artwork used in the application, students could feel relatable to the application and learning activities. Furthermore, as this study was conducted outdoor, a map was prepared for students to navigate themselves in locating the markers around town. An image of the marker was printed on the map as well where students had to locate the same marker at each location

Fig. 10 Blippar application for the outdoor field trip setting

Fig. 11 Map of markers' location for the outdoor field trip setting

to retrieve the learning activity. Students' artwork was also used in designing this map with similar reasons. Students who contributed were given an opportunity to showcase their work to their peers (Fig. 11).

With several other minor amendments made, including inserting the allocated marks for each question to allow students to estimate how much should they contribute for each question, the application was ready for the field trip. Similarly, students were provided with Android tablets and a pair of headsets (as shown in Fig. 12). Although students were grouped in fours, students were allowed to visit

Fig. 12 Students using the application in outdoor field trip setting

any location at any sequence. Researchers and teachers were assigned to accompany each group to ensure the safety of the students and to observe the students' learning process.

Once the group arrived at a location, students seek the location's marker as printed on the map provided. With the marker located, students used the application to scan the marker and begin the learning activity. At the main scene of the learning activity, students could select any topic to begin with. After completing all the learning content, including the short video, student proceeded to complete the quiz for each learning activity. Once the group had completed the learning activity and its quiz, the group moved on to the next location until all four locations were visited and all learning activities were completed. Thereafter, students were required to complete a similar questionnaire as the classroom setting activity to provide their feedback on their learning experience, compare both classroom setting and outdoor field trip setting's learning experience, and suggest improvements that might better improve their future learning experience. Some of the feedbacks received are as shown in Table 7.

From the feedback received from students for the classroom setting, changes and amends of the research design were made to improve the learning experience for students. The changes made included changing the learning setting from classroom setting to outdoor learning setting, the layout of the main scene in the application and including students' involvement in the application designing process. With these changes and amends made, the learning application was used by students during an outdoor field trip learning setting. Similarly, students shared their feedback after completing the learning activities. Students shared that it could be better if there were less open-ended questions in the learning application as during an outdoor field trip learning setting, students were mainly on the go; hence, it might be difficult for students to answer open-ended questions. Students also suggested that the learning process could be designed as a competition to increase the excitement and engagement of students. Furthermore, students also suggested that hands-on activities could be included in the learning process since they are at the location itself.

Table 7 Result of the feedback questionnaire of the outdoor field trip setting (adopted from Chew et al., 2017b)

What improvement could be done by this application in order to make it more enjoyable?	
• More video could be included • Lesser open-ended questions as it takes time to complete	• Make it a competition among students • Creative activity could include other activities like photography or games
In your opinion, what are the benefits of learning with this application?	
• Get to be at the actual landmark and understand its surrounding environment • It made me more interested to know more about the local history and culture • I enjoyed the questions asked in the application as it makes me think	• Get to speak to the people or owner of the shop to understand further • It improves my learning as it was easy to understand • Got a better impression of the learning topic
Compared with the previous session in the classroom, what are the benefits of this session and what are some improvements that could be made?	
Benefit: • Could get a better view of the item as compared to viewing it on the tablet • Get to see the actual item • Easier to understand and have my own experience about the learning topic	**Improvements**: • Internet connection could be improve • Markers were difficult to scan as compared to in classroom • Hands-on activity at the landmark could be inserted into the learning as well

4 Discussion and Conclusion

Both research presented in this chapter utilized the augmented reality technology in designing the learning application of the research. The quiz results from both research had shown that the designed learning applications were effective in improving students' learning performance in the respective learning subjects (Chew et al., 2017a, b). The questionnaire and interview results of both research showed that the usage of the augmented reality technology had increased students' interest in the learning topic, and the feedback received from the students was positive. The students were keen in sharing with the teachers and researchers their thoughts regarding the applications, and were eager to have more learning contents and requested that additional information of existing learning topic be included in future (Chew et al., 2017b).

From the study by Chew et al. (2017a), it was found that students enjoyed learning about the scientific topic through hands-on activity. Students not only were able to understand the topic better, but they expressed that they were able to understand the reason on the importance of learning the scientific topic, and how it played a role on their daily life. As students were not taught previously regarding the scientific topic, however, through self-exploration, the continuous "try and error" process and discussion with peers, students managed to master the scientific topic well in a manner which was more comfortable for students to ask questions when they did not understand. Besides gaining new knowledge in terms of understanding the scientific topics, students who participated in explaining their understanding of the topic to their peers shared that this allowed them to not only enhance their own understanding of the topic, but it also provided students the opportunity to structure their thoughts and manner of expressing their understanding. This was evident as when their peers did not understand their explanation, students had to try to express their thoughts in a different manner, so that their peers could understand what they meant.

In terms of collaborative learning, in Chew et al. (2017a) study, there had been the free-rider problem where students were reluctant to participate or contribute to the group. This is a common problem when it comes to collaborative learning, especially among elementary students. This was mainly because these students are in the opinion that the group would accomplish the study goal with or without their contribution, and they do not see the importance of their participation. The other reasons include students were not enjoying the learning process as there might be too many group members in the group, making them feel that their participation was insignificant. In order to solve the problem of free riders, specific roles could be given to each individual member of the group, and this could include providing specific information of each member of the group to ensure that each of their individual contributions is vital to the group's success in completing the learning goal. This type of collaborative learning is called Jigsaw classroom. As Tarhan, Ayyıldız, Ogunc, and Sesen (2013) mentioned, "[j]igsaw enhances cooperative learning by making each student responsible for teaching some of the learning issues to the group" (p. 185). This may be incorporated in future research studies on collaborative learning with elementary school students.

Furthermore, both studies had shown the importance of collaboration between elementary schoolteachers and researchers in designing the learning activity and the application involved in the study, which is similarly discussed in Chew et al. (2018) study. The teachers were the main key person who understood the learning needs of the classroom and the students' preferable learning styles and methods. Similarly as mentioned in Chew et al. (2018), it is important that the teachers are clear with the learning objectives of the session, and it would be even better if the teachers could suggest the types of improvements they hope to achieve in the session during the discussion with the researchers at the designing stage of the research. Thereafter, the researchers could provide suggestions and solutions to the teachers and have a discussion with the teachers in deciding which solution best fits the students' learning process and preferably, their learning needs. As researchers, it is important to acknowledge and respect that the teachers understand the needs of their students, and with their input and suggestions, the study could take place with the foreseeable issues removed prior to the conduction of the study.

With the sharing of both studies that had utilized different augmented reality software in designing the learning application, this chapter would like to share some options that are available for teachers and educators who are interested in utilizing the technology. For teachers and educators who have a clear idea on the presentation method and learning pedagogies, they would prefer to utilize for the learning process for their student (such as Chew et al., 2017a), working with a software developer would be more beneficial in terms of more customization could be applied in the application. With much emphasis given to the fact that the teachers and educators have to provide their proposed learning process and learning content along with details on the different features and functions that are expected in the application. However, endless a backend platform that does not involve the knowledge of programming language was also developed during the designing process, teachers and educators might not be able to change the learning topic and learning content on their own. This would leave teachers and educators with much issue if the flexibility to change content was required for their class.

For teachers and educators who are hoping to design their own learning content with existing application which would enable them to have flexibility to change the learning material and contents (such as Chew et al., 2017b), there are numerous available software, applications and platforms available in the market (such as Blippar, Layar and Ausrama). These augmented reality software are readily available on smartphones and tablets. Teacher and educators could easily access the backend platform of these software (usually via their website) to begin the customization process in designing the learning activities for their class. Basic functions and features are usually available, i.e. the usage of image, audio, video, simple question and answer functions, directing to other websites. Teachers and educators can decide on the targeted image used for students to scan in order to enter the designed learning activities. The layout of the augmented item over the targeted image could also be easily customized. However, as compared to the augmented reality software that requires programming language, these simplified augmented reality software would have their limitation in terms of the availability of certain features and functions, the amount of allowed customization, etc. Hence, teachers and educators have to take into consideration these factors when deciding on the sort of augmented reality software used for their classroom.

Augmented reality software allowed teachers and researchers to design different learning activities to better improve the learning experience for students. For different learning topics, with the compliment of the appropriate learning pedagogy for the learning topic, augmented reality technology could evidently assist in providing more engaging and immersive learning environments for students. This would in turn instil deeper interest among students to acquire more information on the learning topic and build long-term memory of the knowledge learnt throughout the learning activity.

Acknowledgements This work was supported by the Intelligent Electronic Commerce Research Center from The Featured Areas Research Center Program within the framework of the Higher Education Sprout Project by the Ministry of Education (MOE) in Taiwan.

References

Ann Haefner, L., & Zembal-Saul, C. (2004). Learning by doing? Prospective elementary teachers' developing understandings of scientific inquiry and science teaching and learning. *International Journal of Science Education, 26*(13), 1653–1674.

Azuma, R. T. (1997). A survey of augmented reality. Presence: Teleoperators and Virtual Environments, 6(4), 355–385.

Bacca, J., Baldiris, S., Fabregat, R., Graf, S., & Kinshuk, (2014). Augmented reality trends in education: A systematic review of research and applications. *Educational Technology & Society, 17*(4), 133–149.

Brown, F. A. (2008). Collaborative learning in the EAP classroom: Students' perceptions. *ESP World, 17*(7), 1–18.

Brown, D., & Warschauer, M. (2006). From the university to the elementary classroom: Students' experiences in learning to integrate technology in instruction. *Journal of Technology and Teacher Education, 14*(3), 599–621.

Capdeferro, N., & Romero, M. (2012). Are online students frustrated with collaborative learning experiences? *The International Review of Research in Open and Distributed Learning, 13*(2), 26–44.

Chen, H. T., Wang, H. H., Lu, Y. Y., Lin, H. S., & Hong, Z. R. (2016). Using a modified argument-driven inquiry to promote elementary school students' engagement in learning science and argumentation. *International Journal of Science Education*, *38*(2), 170-191.

Chew, S. W., Lin, I.-H., Huang, Y.-C., Kinshuk, & Chen, N.-S. (2017a). Collaborative learning in elementary science supported by learning by inquiry and augmented reality. In *Proceedings of the 25th International Conference on Computers in Education* (pp. 240–242). New Zealand: Asia-Pacific Society for Computers in Education.

Chew, S. W., Lin, I.-H., Huang, Y.-C., & Chen, N.-S. (2017b). Cultivating interest in history and culture using augmented reality for elementary students. In *Workshop Proceedings of the 25th International Conference on Computers in Education* (pp. 235–246). New Zealand: Asia-Pacific Society for Computers in Education.

Chew, S. W., Cheng, I. L., Kinshuk, & Chen, N. S. (2018). Exploring challenges faced by different stakeholders while implementing educational technology in classrooms through expert interviews. *Journal of Computers in Education*. https://doi.org/10.1007/s40692-018-0102-4.

Chiang, T. H. C., Yang, S. J. H., & Hwang, G. J. (2014). An augmented reality-based mobile learning system to improve students' learning achievements and motivations in natural science inquiry activities. *Educational Technology & Society, 17*(4), 352–365.

Chu, H. C., Hwang, G. J., Tsai, C. C., & Tseng, J. C. (2010). A two-tier test approach to developing location-aware mobile learning systems for natural science courses. *Computers & Education, 55*(4), 1618–1627.

Dillenbourg, P. (1999). What do you mean by collaborative learning? Collaborative-learning: Cognitive and computational approaches, 1 (pp. 1–15).

Dawley, L., & Dede, C. (2014). Situated learning in virtual worlds and immersive simulations. In *Handbook of research on educational communications and technology* (pp. 723–734). New York, NY: Springer.

Engeln, K., Mikelskis-Seifert, S., & Euler, M. (2014). Inquiry-based mathematics and science education across Europe: A synopsis of various approaches and their potentials. In *Topics and trends in current science education* (pp. 229–242). https://doi.org/10.1007/978-94-007-7281-6_14.

Hsu, Y. S., Chang, H. Y., Fang, S. C., & Wu, H. K. (2015). Developing technology-infused inquiry learning modules to promote science learning in Taiwan. In *Science education in East Asia* (pp. 373–403). https://doi.org/10.1007/978-3-319-16390-1_15.

Hwang, G. J., Chiu, L. Y., & Chen, C. H. (2015). A contextual game-based learning approach to improving students' inquiry-based learning performance in social studies courses. *Computers & Education, 81,* 13–25.

Hwang, G.-J., Wu, P.-H., Chen, C.-C., & Tu, N.-T. (2016). Effects of an augmented reality-based educational game on students' learning achievements and attitudes in real-world observations. *Interactive Learning Environments, 24*(8), 1895–1906.

ITS Training Services. (2014). Five basic elements of cooperative learning. Retrieved from http://tutorials.istudy.psu.edu/cooperativelearning/cooperativelearning4.html.

Kay, K., & Greenhill, V. (2011). Twenty-first century students need 21st century skills. In *Bringing schools into the 21st century* (pp. 41–65). Netherlands: Springer.

Kinshuk, Chen, N. S., Cheng, I. L., & Chew, S. W. (2016). Evolution is not enough: Revolutionizing current learning environments to smart learning environments. *International Journal of Artificial Intelligence in Education*, *26*(2), 561–581.

Laal, M. (2013). Collaborative learning; elements. *Procedia-Social and Behavioral Sciences, 83,* 814–818.

Lazonder, A. W., & Harmsen, R. (2016). Meta-analysis of inquiry-based learning: Effects of guidance. *Review of Educational Research, 86*(3), 681–718.

Lu, S.-J., & Liu, Y.-C. (2015). Integrating augmented reality technology to enhance children's learning in marine education. *Environmental Education Research, 21*(4), 525–541.

Martín-Gutiérrez, J., Fabiani, P., Benesova, W., Meneses, M. D., & Mora, C. E. (2015). Augmented reality to promote collaborative and autonomous learning in higher education. *Computers in Human Behavior, 51,* 752–761.

Mishra, P., & Kereluik, K. (2011, March). What 21st century learning? A review and a synthesis. In *SITE Conference* (pp. 5–236).

Roussou, M. (2004). Learning by doing and learning through play: An exploration of interactivity in virtual environments for children. *Computers in Entertainment (CIE), 2*(1), 10.

Santos, M. E. C., Taketomi, T., Yamamoto, G., Rodrigo, M. M. T., Sandor, C., & Kato, H. (2016). Augmented reality as multimedia: The case for situated vocabulary learning. *Research and Practice in Technology Enhanced Learning, 11*(1), 4.

Smith, B. L., & MacGregor, J. T. (1992). What is collaborative learning? In *Collaborative learning: A sourcebook for higher education* (pp. 10–30). University Park, PA: National Center on Postsecondary Teaching, Learning, and Assessment.

Sung, H. Y., & Hwang, G. J. (2013). A Collaborative game-based learning approach to improving students' learning performance in science courses. *Computers & Education, 63,* 43–51.

Tamir, P. (1990). Considering the role of invitations to inquiry in science teaching and in teacher education. *Journal of Science Teacher Education, 1*(3), 41–45.

Tarhan, L., Ayyıldız, Y., Ogunc, A., & Sesen, B. A. (2013). A Jigsaw cooperative learning application in elementary science and technology lessons: Physical and chemical changes. *Research in Science & Technological Education, 31*(2), 184–203.

van Dijk, A. M., Gijlers, H., & Weinberger, A. (2014). Scripted collaborative drawing in elementary science education. *Instructional Science, 42*(3), 353–372.

Chapter 13
Teaching Technology Design: Practicing Teachers Designing Serious Educational Games

Leonard A. Annetta and Marina Shapio

1 Introduction

1.1 What Is Design Thinking?

Although the concept of design thinking dates back to the 1950s, there is no unique, essential meaning of design thinking; rather, it is a guiding concept used in various theoretical and applied situations and is given meaning within those applications (Johansson-Skoldberg, 2013). Design thinking is a nonlinear approach to problem-solving (Razzouk, 2012).

The nonlinear nature of the design process is further elaborated by Wells (2013) who distinctly states that designing is not a set of pre-programmed events, but instead more of an interactive and experiential activity which requires conscious practical and emotional engagement by each individual involved in the creative and collaborative process. These strategies are relevant to all disciplines and professions (Lindberg, 2010), which makes design thinking applicable across and outside a curriculum. Figure 1 from the Stanford d school is a great illustration of design thinking that we like to refer to when helping others understand how we operationally define the process. The continuum goes a bit further than we did in this particular study as it encompasses the implementation piece that results in a business canvas.

L. A. Annetta (✉)
East Carolina University, Greenville, USA
e-mail: annettal16@ecu.edu

M. Shapio
California State University-Bakersfield, Bakersfield, USA
e-mail: mshapiro1@csub.edu

P. Díaz et al. (eds.), *Learning in a Digital World*, Smart Computing and Intelligence, https://doi.org/10.1007/978-981-13-8265-9_13

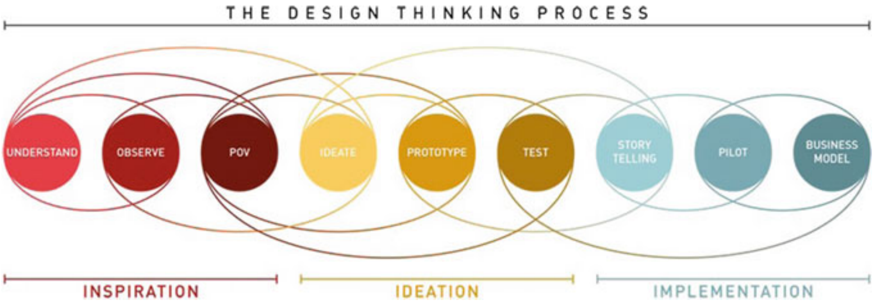


Fig. 1 The design thinking process from the Stanford d school (https://dschool.stanford.edu/resources-collections/browse-all-resources)

1.2 Historical and Theoretical Basis of Design Thinking

Simon (1996) published the first work about design and interest increased over time, with management and business sectors showing interest in the 1980s, followed by scholars in other disciplines and the media in the early 2000s (Johansson-Skoldberg, 2013). Buchannan (1992) helped to shift the nature of design theory from a history of a focus on industry and products toward the more general "design thinking" concept as it currently exists—as a liberal arts concept that can be applied to most anything in order to meet the needs of complex human problems (Kimbell, 2011).

1.3 Design Thinking in Education

According to Razzouk (2012) design thinking, one of the central tenets of engineering can afford great benefits to twenty-first-century education as it affords opportunities for students to engage in creative approaches to problem-solving and finding solutions. Design thinking, when applied to a discipline, engages would-be designers in a process which is inherently "iterative, exploratory, and sometimes chaotic" (p. 336) but which ideally culminates with a satisfactory solution to the original problem (Razzouk, 2012). Scheer, Noweski, and Meinel (2012) agree within their assessment of design thinking as a valuable tool in working toward building twenty-first-century skills, an approach that is in alignment with well-known theoretical and applied pedagogies of Dewey, constructivism, and experiential learning.

Lindberg (2010) discussed design thinking as an evolving and meta-disciplinary discourse, which has been invoked and applied in various areas, although not necessarily in a congruent way. There seem to be two predominant camps in the design thinking literature: Positivistic versus constructivist. Constructivists align with the "wicked problems" approach. Cross, Buchanan, and others devised the normative approach to design thinking and formulated some guidelines in the 1990–2000s. The last norm, and perhaps the most applicable to the realm of education, is the use of "complementary team members." This norm supposes that team members should complement each other in regard to their backgrounds, as one person cannot possibly know all that there is to know in the world. In the same way, that design thinking frees professional teams from "mono-disciplinary" restrictions, the intensely team-based approach may be useful in both balancing and also extending the academic capabilities of diverse groups of learners in the classroom. Students can learn design thinking skills provided they are embedded within meaningful contexts for practice and application, such as learning experiences rooted in project-, problem-, and inquiry-based pedagogy (Razzouk, 2012). Conversely, a more positivistic approach employs the scientific method during the process (but not always) and a state of trial-and-error ensues until an acceptable final product is attained. This is assumed, as most positivistic approaches, that there is an underlying truth that can be deduced through the scientific method.

With a call for more design challenges through the Next Generation Science Standards, teachers are often either never taught how to construct design activities or do not feel comfortable deploying design challenges in their classrooms.

We conducted an early intervention study from an instructional technology graduate course developed for science education graduate students, which used the existing curriculum for introducing Design, Engineering, and Technology (DET) into the classroom. The course is project-based and one of the projects was to play a series of Serious Educational Games (SEG) (Annetta, 2008) and then use a game design document template (Appendix B) constructed and modified over 15 years of funded grants projects to design their own game. Students never actually used the game development technology to build their designs but rather learned the baseline design process without the multiple iterative nature of designing a technology. Students designed their respective games in the template provided to them. The game had to teach a science concept that they either had difficulty teaching and/or their students had difficulty learning. The thought process behind this assignment was to challenge student thinking as designers in a technology-rich environment.

Students created an original design document and then shared it with three classmates that were predetermined as a group based on discipline. Based on feedback from their group members, students were asked to redesign their SEG. The instructor then read that version of the document, an expert in SEG design and development, and further feedback was given to the student who then had to redesign another iteration of the document. This process was a microcosm of game design. Had the student actually constructed and playtested the game then there would likely be several more iterations of the design document before a finished product was completed.

2 Methods

This study was set in a large mid-Atlantic university in the United States. Students in the course were science education graduate students who mostly worked in a K-12 setting but there was one student who worked in a nonformal science education environment. The course was delivered online, asynchronously with weekly synchronous videoconferences with the instructor as needed.

Seventeen students enrolled in the course, completed a survey before the assignment began, and then completed a posttest 1 week after it ended. Fourteen females and three males comprised the participants. Not all participants opted-into the study. Of the final 14 who did, eleven females and all three males comprised the final study sample.

2.1 Data Collection and Instrumentation/Research Design

An instrument was created to measure if there is an increase in design thinking before and after participating in the design activities described in this study. This was conducted by modifying several engineering designs and design thinking surveys while also adding our own items to better assess DET in our context. Forty questions on a four-point Likert scale ranging from Strongly Agree to Strongly Disagree resulted in a pre- and posttest of students. Items of the survey ranged from ascertaining perceptions of what engineers actually do to the respondent's interest in Design, Engineering, and Technology (DET). A list of the survey items is in the Appendix (DET). A list of the survey items is in the Appendix. Pre- and post-surveys were administered to measure if a statistically significant gain was achieved. They do not necessarily have to be used to assess learning gains. We were measuring design thinking in this study and not learning.

2.2 Analysis

Due to lower numbers in this study, a paired-sample t-test was performed to look for mean differences from pre- to post-survey responses. We also wanted to standardize each of the tests, pre and post, to ensure reliability. To that end, we performed Cronbach's Alpha on each test independently and together and found the instrument reliable above 0.80.

3 Results

Results from the analyses are as follows. Table 1 illustrates mean differences through the paired-sample t-test. Eighteen students in the class were given the survey but only 14 decided to participate in the study. Hence, we are only reporting results from those 14 students (11 females and 3 males).

Table 1 Descriptive statistics for design thinking surveys. Means are represented as overall sums of survey results

		Mean	N	Std. deviation	Std. error mean
Pair 1	Pre	2.3554	14	0.38144	0.10194
	Post	2.1018	14	0.42090	0.11249

Using an alpha at 0.05, we see statistically significant mean differences from pretest to posttest. Correlations and two-tailed significance (Table 2) suggest interesting results, which are described in detail in the implications section.

Overall, results of the paired-sample *t*-test indicated that there was a significant difference in pre-design thinking scores (M = 2.3554, SD = 0.38144) and post-design thinking scores (M = 2.1018, SD = 0.42090), $t(13) = 2.935$, $p < 0.05$.

To be certain the survey was reliable, we performed a Cronbach's alpha test on the pretest, posttest, and combined pre and post. Tables 3 and 4 suggest strong reliability from the small sample of participants in the study.

4 Implications

The results are interesting on several levels. First, it is important to note that the sample was small, and thus future study needs to occur to corroborate these results. That said, the instrument showed strong reliability and researchers looking to investigate DET in future studies can use this survey to answer perceptual questions on the topic.

Arguably, the most interesting result is that mean differences were slightly skewed toward results from the pretest. Understanding that the survey was self-report, it is actually not surprising that the results were as presented. Many students expressed confidence in their design ability. It was not until the rigor of designing an SEG was experienced did the participants understand the challenges faced as a designer.

Creativity alone cannot carry a design. One needs to understand the iterative process and be prepared to revise and retest their design several times until a satisfactory product is achieved. If we revisit Fig. 1, we can start to understand the complexity of DET from a designer's perspective. The ***Inspiration*** component is somewhat easy. However, moving along the continuum, the ***Ideation*** becomes increasing more challenging until the ***Implementation*** component is reached. As our study might suggest, it is not until that final section does the designer realize the process takes time, energy, and some self-reflection.

Asking science teachers to implement DET into their classroom presents some pushback. An already packed curriculum challenges the time teachers have to cover material and students have to complete project-based elements that require them to think like a designer/engineer. In the pretest, it is not surprising that teachers who did not fully understand DET would respond to the survey questions in such a way that they take a Utopian stance on how to implement such an activity with their students. It was not until they themselves were asked to accomplish a DET task did they have

Table 2 Paired-sample t-test for design thinking surveys for overall survey results

		Paired differences					t	f	Sig. (2-tailed)
		Mean	Std. deviation	Std. error mean	95% confidence interval of the difference				
					Lower	Upper			
Pair 1	Pre—post	0.25357	0.32327	0.08640	0.06692	0.44022	2.935	3	0.012

Table 3 Reliability of independent pre/posttest

Cronbach's alpha	Cronbach's alpha based on standardized items	No. of items
0.908	0.921	40

Table 4 Reliability of combined pre/posttest

Cronbach's alpha	Cronbach's alpha based on standardized items	No. of items
0.938	0.946	80

to question the feasibility of infusing such endeavors into their teaching repertoire. To this end, we hope this small study encourages readers to continually challenge teachers, preservice, and inservice alike, to DET processes. We need to dare our students to think laterally and creatively and that will not happen unless teachers understand and feel a great level of comfort in DET.

Acknowledgements This material is based upon work supported by the National Science Foundation under REAL (award# 1420448) entitled **Self-regulation of Science Learning in the Context of Educational Game Creation: A Study of Middle School Students with Learning Disabilities**. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

Annetta, L. A. (2008). *Serious educational games: From theory to practice* (p. 83). Amsterdam, The Netherlands: Sense Publishers.

Buchanan, R. (1992). Wicked problems in design thinking. *Design Issues, 8*(2), 5–21.

Johansson-Sköldberg, U., Woodilla, J., & Çetinkaya, M. (2013). Design thinking: Past, present and possible futures. *Creativity and Innovation Management, 22,* 121–146.

Kimbell, L. (2011). *MBA elective in designing better futures*. Retrieved April 16, 2018, from http://wwww.designingbetterfutures.wordpress.com/.

Lindberg, T., & Meinel, C. (2010). *Design thinking in IT development? Electronic colloquium on design thinking research* (Report No. 1).

Razzouk, R., & Shute, V. (2012). What is design thinking and why is it important? *Review of Educational Research, 82*(3), 330–348. https://doi.org/10.3102/0034654312457429.

Scheer, A., Noweski, C., & Meinel, C. (2012). Transforming constructivist learning into action: 'Design thinking' in education. *Design and Technology Education, 17*(3), 8–19.

Simon, H. A. (1996). *The sciences of the artificial*. MIT press.

Wells, A. (2013). The importance of design thinking for technological literacy: A phenomenological perspective. *The International Journal of Technology and Design Education, 23,* 623–636.

Chapter 14
Student and Teacher's Perceptions Toward the in-Game Card as Educational Reward (ICER) Moodle Plugin

Rita Kuo, Maiga Chang, Zhong-Xiu Lu and Cheng-Li Chen

1 Introduction

Encouraging students' motivation could help students succeed in academic achievements (Dev, 1997). Therefore, giving rewards to students is frequently used in the classroom. Studies show that educational rewards can improve students' learning performance (Winefield, Barnett, & Tiggemann, 1984); however, the effectiveness of the traditional educational reward is limited when the reward is unattractive to students (Marinak, 2007).

The research shows that 67% of learners in the United States have used digital games in learning (Statista, 2018). Considering adopting the traditional educational reward system to the gamer generation, the research team has designed a reward plugin on Moodle for dispatching game-based educational rewards to students based on their performance in the learning activities (Chen, Chang, & Chang, 2016; Chen et al., 2017). To understand the usability of Chen's research, this research aims to investigate how students and teachers perceived using in-game cards as educational rewards in learning activities.

The next section introduces the game-based educational rewards and the Moodle plugin designed by the research team. The design of accessing students and teachers'

R. Kuo (✉)
Department of Computer Science and Engineering, New Mexico Institute of Mining and Technology, Socorro, USA
e-mail: rita.mcsl@gmail.com

M. Chang · Z.-X. Lu · C.-L. Chen
School of Computing and Information System, Athabasca University, Athabasca, Canada
e-mail: maiga.chang@gmail.com

Z.-X. Lu
e-mail: zhongxiulu814@gmail.com

C.-L. Chen
e-mail: eric.chenglichen@gmail.com

P. Díaz et al. (eds.), *Learning in a Digital World*, Smart Computing and Intelligence, https://doi.org/10.1007/978-981-13-8265-9_14

perceptions in the game-based educational rewards is introduced in Sect. 3. Section 4 analyzed the data we collected from the experiment. The findings and suggestions are listed in Sect. 5. Section 6 summarizes the research and discusses the possible future works.

2 In-Game Card as Educational Reward (ICER) Moodle Plugin

Trading card game is a type of card game in which players use the cards they collected to compete with other players (Pittman & GauthierDickey, 2013). It has been used in teaching host defense (Steinman & Blastos, 2002), weather and climate (Klopfer, Sheldon, Perry, & Chen, 2012; Sheldon et al., 2010), human immune system (Su, Chen, & Lin, 2014), etc. The research team has developed Online Trading Card Game which is used for discipline independent educational rewards (Chen, Kuo, Chang, & Heh, 2009; Chen, Kuo, Chang, & Heh, 2017).

As Fig. 1 shows, teachers can deliver the in-game cards as educational rewards in any course, grade, and school level based on students' performance in the learning activities on the e-learning system. Students can use the reward cards to fight with their fellows in the Online Trading Card Game. In order to be in the higher rank in the game, students need to get higher level cards as well as rarer cards, which they could only get from the e-learning system when they perform better in the learning activities. Therefore, getting better cards in the Online Trading Card Game becomes an intrinsic motivation to students and they would like to work harder in the learning activities.

However, dispatching rewards to students one by one is a heavy burden for teachers. In-game Card as Educational Reward (ICER) Moodle plugin is developed to build a bridge between the e-learning system and the Online Trading Card Game (Chen, Chang, & Chang, 2016; Chen et al., 2017). Teachers can easily use the ICER

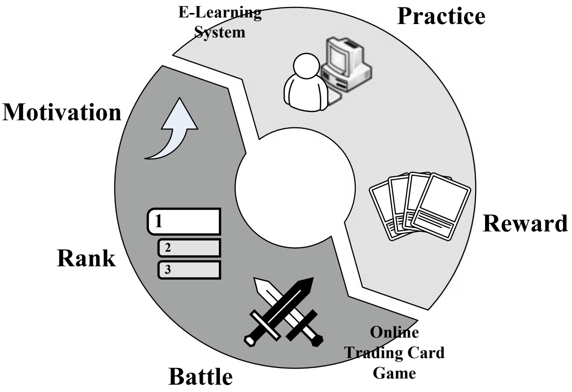
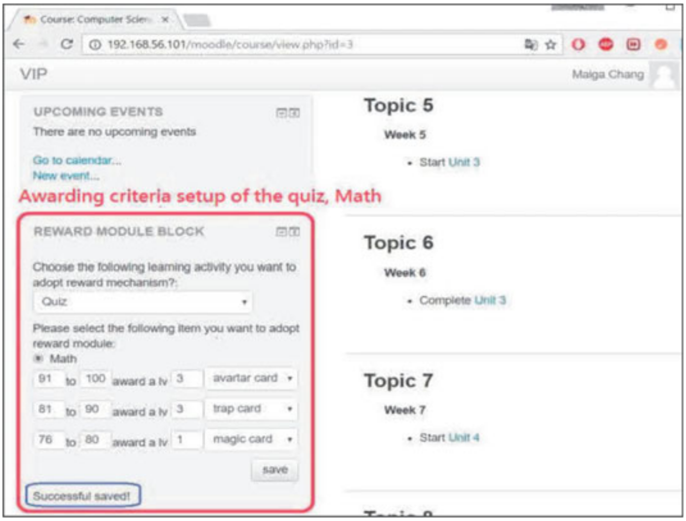


Fig. 1 Motivation enhancement cycle between e-learning system and online trading card game

Moodle plugin to set up the criteria of giving rewards based on students' performance in learning activities, such as quizzes, discussion forum, homework, etc. Figure 2 shows an example of how teachers set up the awarding criteria for the "Math" quiz: students who receive marks from 91 to 100 for the quiz will receive a level 3 avatar card, from 81 to 90 for a level 3 trap card, from 76 to 80 for a level 1 magic card, and below 75 for nothing.

On the other hand, after students finish a learning activity on Moodle, they should receive correspondent rewards; however, they do not know what rewards they get as Fig. 3a shows because they have not given Moodle permission of accessing their card collection information in the online Trading Card Game. After the Trading Card Game button in Fig. 3a is clicked, students will be redirected to the Permission Granting page on the online Trading Card Game server.

As Fig. 4a shows, students need to enter their username and password of the game and tell the system which permission(s) they would like to grant to Moodle



There are no upcoming events

Awarding criteria setup of the quiz, Math

Choose the following learning activity you want to adopt reward mechanism?: Quiz

Please select the following item you want to adopt reward module:

● Math

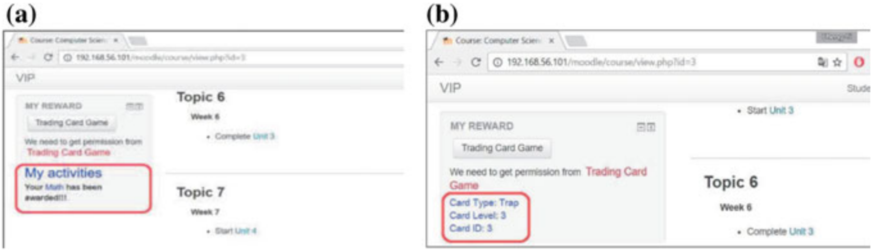
91 to 100 award a lv 3 avartar card

81 to 90 award a lv 3 trap card

76 to 80 award a lv 1 magic card

Successful saved!

Fig. 2 Reward module block for teachers to set up awarding criteria for the "Math" quiz

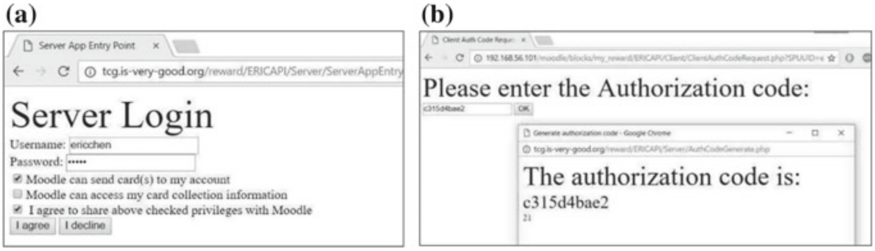


We need to get permission from Trading Card Game

Your Math has been awarded!!!

Card Type: Trap
Card Level: 3
Card ID: 3

Fig. 3 My reward block in Moodle: **a** before authorizing Moodle to give cards to the game server; **b** after the authorization



Server Login

Username: ericchen

Password: •••••

☑ Moodle can send card(s) to my account

☐ Moodle can access my card collection information

☑ I agree to share above checked privileges with Moodle

Please enter the Authorization code:

c315d4bae2

The authorization code is:

c315d4bae2

21

Fig. 4 Authorizing Moodle the permission of accessing students' information in the game server: **a** granting particular permission for Moodle; **b** entering authorization code generated by the game server on Moodle

by selecting specific checkbox(s), for instances, allowing Moodle to send reward cards to the game or to browse their card collection in the game. After selecting the permissions, the game generates an authorization code for students entering when they are redirected back to Moodle as Fig. 4b shows. This process keeps students' private data (e.g., student ID) in Moodle and the game remaining unknown for the other application.

After the permission is granted by Moodle, students can find out what types of cards they have got for a learning activity as Fig. 3b shows. With the ICER Moodle plugin, the online Trading Card Game can be integrated into Moodle smoothly without leaking students' private information in both of the applications.

3 Research Method

The research team has two hypotheses and four moderators regarding how and what factors will affect teachers' and students' attitude toward the ICER Moodle plugin as Fig. 5 shows.

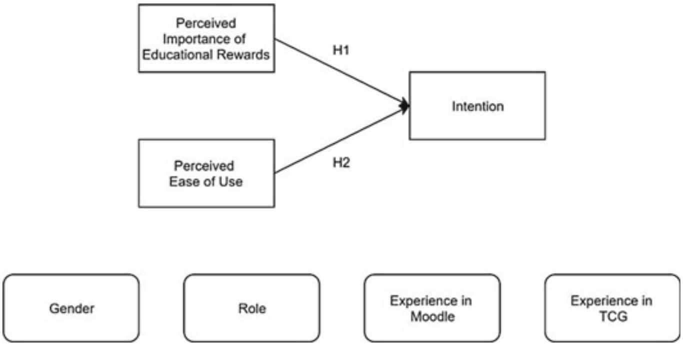


Fig. 5 Hypotheses and the moderators of ICER Moodle plugin

The hypotheses are

- H1: Participants' perceived importance of educational rewards will affect their intention of using ICER Moodle plugin in the future.
- H2: Participants' perceived ease of use toward ICER Moodle plugin will affect their intention of using the plugin in the future.

The moderators are

- Gender: It is used to understand whether the participant is a male or a female. Gender gap is always an important issue in the adoption of new technology. Some studies found out that males have more positive attitudes toward new technologies than females (Durndell & Thomson, 1997; Whitely, 1997). With better understanding of gender difference in acceptance toward learning technology, researchers can design a better product or learning process to overcome the gender gap (Ong & Lai, 2006).
- Role: It is used to understand the participant is a teacher or a student. Christensen (2002) argued that the difference in attitudes toward learning technology between students and teachers might increase anxiety when using the new techniques. This study would like to investigate whether or not teachers and students have different attitudes toward ICER Moodle plugin in order to find out the proper way to adopt the new educational reward system in teaching.
- Experience in Moodle: It is used to understand the participant's past experience in Moodle, including whether or not the participant has heard Moodle as well as whether or not the participant has used Moodle. The research team would like to know whether or not participants who have used Moodle will have higher intention of using ICER Moodle plugin in the future.
- Experience in TCG: It is used to understand the participant's past experience in trading card games, including whether or not the participant has heard any trading card games, whether or not the participant has played any trading card games, and whether or not the participant has seen others playing any trading card games. The research team would like to see if participants who have more experience in any trading card games have higher intention of using in-game cards as educational rewards.

Finding teachers to participate in the evaluation is not easy. To get both teachers and students' views toward ICER Moodle plugin, the research team needs to recruits teachers and students from different cohorts. The educational-related conference is a good place to recruit teachers for the evaluation. Therefore, the teachers were recruited from a hands-on workshop jointly held in advanced learning technology in June 2017 in Beijing and 19 participants (7 males and 12 females) participated in the workshop. On the other hand, the research team recruited students from a course given by the Department of Information Management in a north Taiwan university in 2018 Spring semester. Twenty-six students were recruited, including 7 males and 19 females. In the experiment process, the research team demonstrated how to use ICER Moodle plugin in the beginning. Following with the demonstration, the participants spent 10 min to use the plugin. In the end, the research team asked the participants to

Table 1 Descriptive statistics of participants' Moodle usage experience in two groups

	Have heard Moodle		Have used Moodle	
	Yes	No	Yes	No
Teacher	11 (57.89%)	8 (42.11%)	5 (26.32%)	14 (73.68%)
Student	13 (50.00%)	13 (50.00%)	7 (26.92%)	19 (73.08%)
Total	24 (53.33%)	21 (46.67%)	12 (26.67%)	33 (73.33%)

Table 2 Descriptive statistics of participants' trading card games experience in two groups

	Have heard		Have played		Have seen	
	Yes	No	Yes	No	Yes	No
Teacher	14 (73.68%)	5 (26.32%)	7 (36.84%)	12 (63.16%)	14 (73.68%)	5 (26.32%)
Student	21 (80.77%)	5 (19.23%)	11 (42.31%)	15 (57.69%)	22 (84.62%)	4 (15.38%)
Total	35 (77.78%)	10 (22.22%)	18 (40.00%)	27 (60.00%)	36 (80.00%)	9 (20.00%)

fill out a questionnaire asking them their perceived importance of educational reward, perceived ease of use toward the ICER Moodle plugin, and intention of using the plugin in the future.

After collecting the data, the research team investigated the participants' past experience in Moodle and trading card games. Table 1 shows that 53.33% of participants have heard about Moodle before but only 26% of total participants have used Moodle. There is no significant difference between teachers and students whether they have heard about Moodle before (χ^2 (1, $N = 45$) = 0.275, $p < 0.413$) nor they have used Moodle (χ^2 (1, $N = 45$) = 0.002, $p < 0.619$).

In trading card game experience, 77.78% of participants have heard what trading card game is and 80% have seen other people playing trading card games. However, only 40% of participants have played any trading card games before. There is also no significant between teachers and students in their past experience in trading card games. The results of the chi-square tests corresponding to participants have heard trading card games, have played trading cards, and have seen others playing trading card games are χ^2 (1, $N = 45$) = 0.319 where $p < 0.416$, χ^2 (1, $N = 45$) = 0.137 where $p < 0.477$, and χ^2 (1, $N = 45$) = 0.820 where $p < 0.297$ (Table 2).

4 Analysis

The research team used SPSS 20.0 to verify the validity and reliability for the Importance of Educational Reward (IER) and Perceived Ease of Use (EoU) factors in the questionnaire. The Cronbach's Alpha value of Importance of Educational Reward is 0.919, which sites on "excellent" range and shows that questionnaire is reliable (Georage & Mallery, 2010). The analysis result, as well as the questions, is listed in Table 3. The item description in Table 3 with pair brackets ([…]) indicates

Table 3 Validity analysis result for the questionnaire in the Importance of Educational Reward

Item		Factor
		1
Factor 1: Importance of Educational Reward (IER)		
I8:	I believe [students/I] will work harder in the learning activities (e.g., doing homework, participating in discussion) if [they/I] can get rewards through working on them	0.903
I7:	Once [the student/I] achieves the criteria of the getting rewards in the learning activity, [he/she/I] can get the cards from Trading Card Game as the reward	0.882
I3:	A course should have a rewarding mechanism	0.846
I1:	If a course has a rewarding mechanism, [students/I] will finish the learning activities in the course faster	0.820
I9:	[I believe students/I] prefer [they/I] can get rewards from all learning activities	0.816
I2:	If a course has rewarding mechanism, [students/I] will concentrate [their/my] attention more	0.803
Eigenvalue		4.292
% of variance		71.541
Overall $\alpha = 0.919$, total variance explained is 71.541%		

Table 4 Validity analysis result for the questionnaire in Ease of Use

Item		Factor
		1
Factor 1: Perceived Ease of Use (EoU)		
I5:	I believe [students/most of the people] can easily learn how to authenticate Moodle dispatching cards in the Trading Card Game as a reward	0.818
I4:	The ways of getting cards in Trading Card Game through different learning activities are similar	0.802
I6:	I still remember the process of how [students authorizing/to authorize] Moodle to give cards to [themselves/me] in Online Trading Card Game as a reward	0.786
Eigenvalue		1.930
% of variance		64.320
Overall $\alpha = 0.720$, total variance explained is 64.320%		

the difference description in teachers and students' questionnaire. The description before the slash (/) is for teachers, and the one after the slash is for students.

The Cronbach's Alpha value of Ease of Use is 0.720, which sits on "acceptable" range. The result is shown in Table 4.

Table 5 Correlation analysis between two factors (Importance of Educational Reward and Perceived Ease of Use) and Intention of ICER usage

	IER	EoU
Pearson correlation	0.600	0.660
Sig.	0.000	0.000
N	45	45

IER: Importance of Educational Reward; EoU: Perceived Ease of Use

Table 6 Independent t-test result for Importance of Educational Reward (IER) and Perceived Ease of Use (EoU) in teachers' and students' group

		Descriptive statistics			*t*-test		
		N	Mean	SD	*t*	*df*	*p*
IER	Teacher	19	4.21	0.464	2.252	43	0.029*
	Student	26	3.74	0.831			
EoU	Teacher	19	3.70	0.442	2.729	43	0.009**
	Student	26	3.18	0.744			

$^{*}p < 0.05$, $^{**}p < 0.01$

There is only one 5-point Likert scale item (5 for "Strongly Agree" to 1 for "Strongly Disagree") in the Intention factor, which is asking whether participants agree "I would like to use Moodle ICER Moodle plugin in all the courses" or not. The average rating from all participants is 3.58 with 0.892 standard deviation. There are 42.2% of total participant rated Neutral and 51.1% rated Agree or Strongly Agree. The result shows that most of the participants give positive responses to the intention of using ICER Moodle plugin in the future.

To understand if there is a significant difference between teachers' and students' intention of using ICER Moodle plugin, *t*-test is applied in the analysis. The result shows that there is no significant difference in teachers (M = 3.84, SD = 0.834) and students (M = 3.38, SD = 0.898) groups; $t(43) = 1.739$, $p = 0.089$. In the next step, the research team verifies the two hypotheses in Fig. 5. The results in Table 5 show that both participants' Perceived Importance of Educational Rewards (IER) and Perceived Ease of Use (EoU) factors have a positive correlation to Intention of ICER Usage significantly.

Furthermore, the research team finds out that there is a significant difference between teachers and students in their Perceived Importance of Educational Rewards as well as the Perceived Ease of Use in ICER Moodle plugin. Teachers believe educational rewards are important to students in engaging students' learning motivation; they also give higher score toward the ease of use of the ICER Moodle plugin. The test results are listed in Table 6.

The research team also evaluated whether the other moderators (gender, past experience in Moodle, and past experience in trading card games) would affect participants' intention of using ICER Moodle plugin. First of all, gender is examined. The results show that gender is not the factor which affected participants' perceived

Table 7 Independent t-test result for Importance of Educational Reward (IER), Perceived Ease of Use (EoU), and Intention of ICER Moodle plugin in future usage in gender

		Descriptive statistics			*t*-test		
		N	Mean	SD	*t*	*df*	*p*
IER	Male	14	4.04	0.979	0.594	43	0.555
	Female	31	3.90	0.604			
EoU	Male	14	3.36	0.902	−0.282	43	0.779
	Female	31	3.42	0.571			
Intention	Male	14	3.36	1.216	−1.119	1.704	0.371
	Female	31	3.68	0.702			

Table 8 Independent t-test result for Importance of Educational Reward (IER), Perceived Ease of Use (EoU), and Intention of ICER Moodle plugin in participants' past experience in Moodle usage

			Descriptive statistics			*t*-test		
			N	Mean	SD	*t*	*df*	*p*
Have heard Moodle	IER	Yes	24	4.06	0.602	1.226	43	0.227
		No	21	3.80	0.851			
	EoU	Yes	24	3.47	0.564	0.758	43	0.453
		No	21	3.32	0.800			
	Int	Yes	24	3.63	0.770	0.376	43	0.709
		No	21	3.52	1.030			
Have used Moodle	IER	Yes	12	4.00	0.711	0.341	43	0.735
		No	33	0.39	0.750			
	EoU	Yes	12	3.47	0.558	0.426	43	0.673
		No	33	3.37	0.726			
	Int	Yes	12	3.67	0.778	0.399	43	0.692
		No	33	3.55	0.938			

IER: Importance of Educational Reward; EoU: Perceived Ease of Use; Int: Intention of using ICER Moodle plugin in the future

importance of educational reward, perceived ease of use, and intention of using ICER Moodle plugin in the future as Table 7 shows.

The next moderator the research team investigated was participants' past Moodle experience. Two questions were asked for understanding participants' past Moodle experience, which are "Have you heard of Moodle before?" and "Have you used Moodle before?" The research team uses *t*-test to evaluate whether the past Moodle experience will affect participants' intention of using ICER Moodle plugin in the future. The results are listed in Table 8 which shows that there is no significant difference in intention of using ICER Moodle plugin between participants who have and have no experience in Moodle.

Table 9 Independent t-test result for Importance of Educational Reward (IER), Perceived Ease of Use (EoU), and Intention of ICER Moodle plugin in participants' past experience in trading card games

			Descriptive statistics			*t*-test		
			N	Mean	SD	*t*	*df*	*p*
Have heard TCG	IER	Yes	35	3.88	0.786	−1.037	43	0.306
		No	10	4.15	0.475			
	EoU	Yes	35	3.41	0.715	0.168	43	0.867
		No	10	3.37	0.577			
	Int	Yes	35	3.60	0.914	0.310	43	0.758
		No	10	3.50	0.850			
Have played TCG	IER	Yes	18	3.79	0.900	−1.134	43	0.263
		No	27	4.04	0.594			
	EoU	Yes	18	3.35	0.780	−0.387	43	0.701
		No	27	3.43	0.619			
	Int	Yes	18	3.39	1.037	−1.165	43	0.250
		No	27	3.70	0.775			
Have seen others playing TCG	IER	Yes	36	3.92	0.770	−0.274	43	0.786
		No	9	4.00	0.596			
	EoU	Yes	36	3.43	0.698	0.506	43	0.615
		No	9	3.30	0.634			
	Int	Yes	36	3.58	0.906	0.083	43	0.935
		No	9	3.26	0.882			

The last moderator in the evaluation was participants' past experience in trading card games. "Have you heard of trading card games?", "Have you played trading card games?", and "Have you seen others playing trading card games?" are the questions asked in the questionnaire. The research team also uses *t*-test to examine whether the past experience in trading card games will affect participants' intention of using ICER Moodle plugin in the future. The results show that there is no significant difference between participants with more trading card game experience and those who have less as Table 9 shows.

5 Findings

The analysis results in the previous section show that the two hypotheses are supported: participants who have perceived more positive on the importance of educational rewards or perceived more positive ease of use toward ICER Module have the higher intention of using ICER Moodle plugin in the future. The research team also discovers some important and unexpected findings.

5.1 Important Findings

Based on the analysis results in Sect. 4, more than half of the participants said they Agree or Strongly Agree with "I would like to use ICER Moodle plugin in all the courses." Only three participants (6.7%, one teacher and two students) Disagreed or Strongly Disagreed it. The results show that using ICER Moodle plugin in a course is attractive. Moreover, there is no significant difference between teachers' and students' responses to this question showing that both teachers and students agree using ICER Moodle plugin could help students in the learning process.

Even there is no significant difference between teachers and students for their intention of using ICER Moodle plugin, the researchers find out that teachers have stronger beliefs in educational rewards are important in engaging students' learning motivation, compared to students. The result indicates that teachers have higher intention of using reward mechanism in teaching. If we can persuade teachers that students can be engaged by getting cards as educational reward, teachers might have a higher intention of using ICER Moodle plugin in the future.

The results in Table 6 reveal another question: why students give lower score for the Perceived Importance of Educational Rewards factor than teachers. The possible reason is that the students might have got unattractive educational rewards like pencils and books before and they do not think those reward will increase their learning motivation. It matches Marinak's study that unattractive educational reward will have no effect for engaging students in learning (Marinak, 2007).

Based on this result, the suggestion to educators is to design a more attractive educational reward in their course is important. Integrating game elements is one of the methods to improve the awarding mechanism as our study result shows. Moreover, other studies indicating that responding positively (Dev, 1997) and applying awarding mechanism in individual competition instead of group competition (Michaels, 1977) could also be considered when designing awarding mechanism in the course.

5.2 Unexpected Findings

The past studies show that gender influences players' performance in game (Efrani et al., 2010). In this case, some people might believe boys have a higher intention of using games for learning. However, Table 7 shows that there is no significant gender difference on the intention of using ICER Moodle plugin in the future; female participants even give higher scores slightly.

The result is similar to Arbaugh's study in 2000 as well as Viber and Gronlund's study in 2013. The possible reason is females usually are more active in the learning process than males (Gonzalez-Gomez, Guardiola, Rodriguez, & Alonso, 2012). On the other hand, Table 7 shows that male participants have stronger belief that educational rewards are important for learning. If the rewards for learning activities are attractive enough, male students might spend more time in the activities in order to get rewards.

Our study results suggest that researchers and educators could design educational rewards for different gender in order to improve their learning motivation. Lucas and Sherry's (2004) study shows that there is gender difference in game preference. Take online Trading Card Game, for example, if the research team would like to attract more male students using cards in game as rewards, adding role-playing or fantasy elements might be useful to get male students engaged.

On the other hand, the analysis results in Tables 8 and 9 show that participants' past experience in Moodle and trading card games will not affect their intention of using ICER Moodle plugin in the future. The result consists with Bourgonjon and colleagues' study in 2010 and 2013 (Bourgonjon et al., 2013; Bourgonjon, Valcke, Soetaert, & Schellens, 2010). Teachers and students accept using games in learning even they have less gaming experience.

According to this finding, the research team suggests researchers to encourage teachers using game elements in teaching or rewarding because most of the students are digital natives (Prensky, 2001). Studies show that games could enhance students' learning motivation easier (Cheng, Kuo, Lou, & Shih, 2012; Yang, Chien, & Liu, 2012). There are also evidence showing that educational game could improve students' academic achievements in science (Sung & Hwang, 2013; Yien, Hung, Hwang, & Lin, 2011) and language courses (Yeh, Hung, & Hsu, 2017).

The research team also finds out another unexpected finding—students give lower scores in Perceived Ease of Use (EoU) factor which has significant difference than teachers' responses; moreover, participants who have played trading card games before also give lower scores in the EoU factor. The possible reason is that students were born in the digital age and they are already familiar with gaming interface in commercial games. When they play the games, they do not need to authorize another system to access their data from another game. However, in ICER Moodle plugin, to make sure the Online Trading Card Game will not know students' private data in Moodle, such as their student id, grades, or courses they took, and the authorization process is required.

The suggestion to the system developers of similar research is to simplify the authorization process and better instruction in the system design. Because students only need to do the authorization process once in the beginning, if the authorization process is simple and students understand they only need to do it once, they might have the higher intention of using the similar system in the future.

6 Conclusion

In-game Card as Educational Reward (ICER) Moodle plugin is designed for connecting Moodle and Online Trading Card Game, an existing educational reward system. This research conducted an experiment to find out what factors will affect teachers and students' intention of using ICER Moodle plugin in the future. The results show that both teachers and students are positive toward their intention of using the ICER Moodle plugin in the future. Moreover, participants' perceived importance of educational rewards and their perceived ease of use toward the system have a positive correlation to their intention of using the plugin in the future. On the contrary, the factors include gender, past experience in Moodle, and past experience in trading card games not influence a person's intention of using ICER Moodle plugin.

This study has some limitations. First of all, the sample size is small. Also, as the participants were recruited from a hands-on workshop in an educational technology conference, only one-fourth of participants have used Moodle before—they might have less intention of using ICER Moodle plugin because they have no needs to use the plugin in their courses. Another limitation is the limited time the research team has to allow participants having comprehensive idea of using the plugin and seeing the effect of giving students in-game card as an educational reward. The participants can only try on the ICER Moodle plugin and do not have opportunity to really use the ICER Moodle plugin in a real course. Furthermore, the limited time the research team has also hindered the researchers from interviewing participants regarding why they rate higher or lower scores for each factor.

To solve these issues, the research team would like to conduct one to two month's experiment in the future. Teachers will be able to use ICER Moodle plugin and set up rewarding criteria for learning activities of their classes and students will receive rewards based on their learning performance. Last but not least, what impact the ICER Moodle plugin would have on students' academic achievement is another research issue that should be further investigated in the future.

References

Arbaugh, J. B. (2000). An exploratory study of the effects of gender on student learning and class participation in an Internet-based MBA course. *Management Learning, 31*(4), 503–519.

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.

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.

Chen, C.-L., Chang, M., & Chang H.-Y. (2016). Educational Resource Information Communication API (ERIC API): The case of Moodle and online tests system integration. In *Proceedings of 3rd International Conference on Smart Learning Environments (ICSLE 2016)* (pp. 225–229).

Chen, C.-L., Zhao, Y., Luo, A., Chang, M., Qian, D., Kuo, R., & Chang, H.-Y. (2017). Educational reward Moodle plug-in. In *Proceeding of the 21st Global Chinese Conference on Computers in Education (GCCCE 2017)* (pp. 211–218).

Chen, P., Kuo, R., Chang, M., & Heh, J.-H. (2009). Designing a trading card game as educational reward system to improve students' learning motivations. In *Transactions on Edutainment, III* (pp. 116–128). Berlin: Springer-Verlag.

Chen, P., Kuo, R., Chang, M., & Heh, J.-H. (2017). The effectiveness of using in-game cards as reward. *Research and Practice in Technology Enhanced Learning, 12*, Article #15.

Cheng, Y. M., Kuo, S. H., Lou, S. J., & Shih, R. C. (2012). The construction of and online competitive game-based learning system for junior high school students. *Turkish Online Journal of Educational Technology, 11*(2), 214–227.

Christensen, R. (2002). Effects of technology integration education on the attitudes of teachers and students. *Journal of Research on technology in Education, 34*(4), 411–433.

Dev, P. C. (1997). Intrinsic motivation and academic achievement: What does their relationship imply for the classroom teacher? *Remedial and Special Education, 18*(1), 12–19.

Durndell, A., & Thomson, K. (1997). Gender and computing: A decade of change. *Computers & Education, 28*(1), 1–9.

Erfani, M., Seif El-Nasr, M., Milam, D., Aghabeigi, B., Lameman, B. A., Riecke, B., … Mah, S. (2010). The effect of age, gender and previous gaming experience on game play performance. In: P. Forbrig, F. Paternó, & A. Mark Pejtersen (Eds.), *Human-computer interaction. HCIS 2010. IFIP advances in information and communication technology* (Vol. 332, pp. 293–296).

George, D., & Mallery, P. (2010). *SPSS for windows step by step: A simple guide and reference 18.0 update* (11th ed.). Boston, MA: Allyn & Bacon.

Gonzalez-Gomez, F., Guardiola, J., Rodriguez, O. M., & Alonso, M. A. M. (2012). Gender difference in e-learning satisfaction. *Computers & Education, 58*(1), 283–290.

Klopfer, E., Sheldon, J., Perry, J., & Chen, V. H. (2012). Ubiquitous games for learning (UbiqGames): Weatherlings, a worked example. *Journal of Computer Assisted learning, 28*(5), 465–476.

Lucas, K., & Sherry, J. L. (2004). Sex differences in video game play: A communication-based explanation. *Communication research, 31*(5), 499–523.

Marinak, B. A. (2007). Insights about third-grade children's motivation to read. *College Reading Association Yearbook, 28,* 54–65.

Michaels, J. W. (1977). Classroom reward structures and academic performance. *Review of Educational Research, 47*(1), 87–98.

Ong, C. S., & Lai, J. Y. (2006). Gender differences in perceptions and relationships among dominants of e-learning acceptance. *Computers in Human Behavior, 22*(5), 816–829.

Prensky, M. (2001). Digital natives, digital immigrants: Part 1. *On the horizon, 9*(5), 1–6.

Pittman, D., & GauthierDickey, C. (2013). Match+ Guardian: A secure peer-to-peer trading card game protocol. *Multimedia Systems, 19*(3), 303–314.

Sheldon, J., Perry, J., Klopfer, E., Ong, J., Chen, V. H. H., Tzuo, P. W., & Rosenheck, L (2010). Weatherlings: A new approach to student learning using web-based mobile games. In *Proceedings of the Fifth International Conference on the Foundations of Digital Games* (pp. 203–208). ACM.

Statista. (2018). *Which digital learning materials do you use in your classroom in a typical week?* Retrieved from https://www.statista.com/statistics/658475/us-classroom-digital-learning-materialsweekly-usage/. Accessed 26 May 2019.

Steinman, R. A., & Blastos, M. T. (2002). A trading-card game teaching about host defence. *Medical Education, 36*(12), 1201–1208.

Su, T., Cheng, M. T., & Lin, S. H. (2014). Investigating the effectiveness of an educational card game for learning how human immunology is regulated. *CBE—Life Sciences Education, 13*(3), 504–515.

Sung, H. Y., & Hwang, G. J. (2013). A collaborative game-based learning approach to improving students' learning performance in science courses. *Computers & Education, 63,* 43–51.

Viberg, O., & Gronlund, A. (2013). Cross-cultural analysis of users' attitudes toward the use of mobile devices in second and foreign language learning in higher education: A case from Sweden and China. *Computers & Education, 69*(1), 169–180.

Whitely, B. E., Jr. (1997). Gender differences in computer related attitudes and behavior: A meta analysis. *Computers in Human Behavior, 13*(1), 1–22.

Winefield, A. H., Barnett, J. A., & Tiggemann, M. (1984). Learned helplessness and IQ differences. *Personality and Individual Differences, 5*(5), 493–500.

Yang, J. C., Chien, K. H., & Liu, T. C. (2012). A digital game-based learning system for energy education: An energy conservation pet. *Turkish Online Journal of Educational Technology, 11*(2), 29–37.

Yeh, Y. T., Hung, H. T., & Hsu, Y. J. (2017). Digital game-based learning for improving students' academic achievement, learning motivation, and willingness to communicate in an english course. In *Proceeding of the 6th IIAI International Congress on Advanced Applied Informatics (IIAI-AAI)* (pp. 560–563).

Yien, J. M., Hung, C. M., Hwang, G. J., & Lin, Y. C. (2011). A game-based learning approach to improving students' learning achievements in a nutrition course. *Turkish Online Journal of Educational Technology, 10*(2), 1–10.

Chapter 15
The GlobalEd 2 Project: Interdisciplinary Simulations Promoting Students' Socio-scientific Literacy

Scott W. Brown and Kimberly A. Lawless

1 Introduction

As we prepare students in our schools today, at all levels (preschool to university), we are focused on both evolving content and skills associated with working together to address important global issues, such as climate change, water resources, energy production, and food security. To address these issues today and in the future, our students in classrooms today will need formal and informal experiences across four critical themes of the twenty-first-century skills literature (see Dede, 2009; Fadel, 2008; Graham, 2015):

- Problem-solving,
- Collaboration and teamwork,
- Critical thinking, and
- Creativity.

These four themes are central to the success of our future citizens and leaders addressing the problems we know we will be facing, and those that will yet emerge in their future. Therefore, we must change the way we prepare our future citizens and leaders so they are well prepared to address these challenges on a global scale—across

---

The authors wish to acknowledge the US Department of Education's Institute for Education Sciences support through grants #R305A080622; #R305A1391895 and #R305A170588. The opinions expressed here are those of the authors and do not represent the position of the United States Department of Education.

S. W. Brown (✉)
University of Connecticut, 249 Glenbrook Road Unit 3064, Storrs, USA
e-mail: Scott.Brown@uconn.edu

K. A. Lawless
College of Education, University of Illinois, 1040 West Harrison M/C 147, Chicago, IL 60607, USA
e-mail: klawless@uic.edu

P. Díaz et al. (eds.), *Learning in a Digital World*, Smart Computing and Intelligence, https://doi.org/10.1007/978-981-13-8265-9_15

nations, cultures, borders, and philosophies. Citizens and leaders in the twenty-first century must be prepared to be skilled all of the four themes stated above and further have both the socio-scientific literacy skills and the social perspective-taking skills to work on a global scale.

We do not live in isolation and, therefore, we are not immune to the effects of world affairs, but rather are affected as members of an interdependent global community, which is why being an educated global citizen is critical, now more than ever before. As such, we must prepare students—the next generation of global citizens, to be fully participating members in this dynamic global environment (Boyer et al., 2004, 2005) because problems such as climate change, water resources, food security, and the generation of energy are not local or national problems to be solved—they are global problems that involve human rights, the global economy, universal healthcare, and a sustainable environment in order to provide affordable access to fresh potable water and nutritious food for all people on planet Earth.

Problem-solving and decision-making in the world today, as we know, are interdisciplinary in nature. Problems rarely exist within solely one domain, nor do the implications and options for solutions fail to encompass interdisciplinary or multidisciplinary issues, whether scientific, social, political, moral, ethical, cultural, environmental, or economic. Further, these problems require the ability to take different social perspectives, so that we may see the world through the eyes of others, in order to understand their perspectives, actions, motives, and attitudes—social perspective-taking (Gehlbach et al., 2008). Finally, in order to push forward solutions, current, and future citizens must also have well-formed and critical communication skills that require two-way dialogue, a back and forth, that crosses both disciplinary boundary lines and cultural stances.

It is the nexus of these three needs, problem-solving, social perspective-taking, and communication, that sits at the heart of the GlobalEd2 (GE2) curriculum. GE2 is a fully developed intervention, consisting of a set of problem-based learning (PBL), online simulations for middle school students that capitalize on the multidisciplinary nature of social studies. GE2 is designed to cultivate a globally literate citizenry by embedding learning in meaningful socio-scientific contexts related to the world in which students currently live (Anderson, 2002; NRC, 1996; Sadler, 2009). Data indicate that GE2 impacts central social studies constructs regarding social perspective-taking, negotiation, styles leadership development, as well as social science knowledge and attitudes (Boyer et al., 2007; Brown et al., 2003; Florea et al., 2003; Gehlbach et al., 2008). Further, efficacy trials data indicate significant pre- to post-student gains on multiple cognitive and affective outcomes in science and literacy, including science knowledge/skills and self-efficacy (Bandura, 1997), and the quality of written scientific argumentation, when compared to students in a normal educational practice (NEP) condition (Brown, Lawless, & Boyer, 2015; Lawless & Brown, 2015).

This chapter is intended to acquaint readers with GE2 and how the simulations work. In addition, we will explore the theoretical underpinnings of GE2 and its pedagogical approach to providing a context-rich simulated environment within which we immerse middle-grade students into the world of global affairs. Finally, we will explore what we have found over the last two decades of research on various iterations of GE2 and where our research will take us in the future. Implications for both educational researchers and practitioners will also be discussed.

2 What Is GE2?

It is October 2016 in an eighth-grade social science classroom in suburban Connecticut. A group of 5 students is huddled around a table with two iPads playing the role of Mexico's environmental science advisors as they read a message from another classroom of students who are playing the role of Japan's environmental science advisors in the GlobalEd 2 simulation. The message says

> Dear Mexican delegates,
>
> We're sorry, but we cannot accept your offer, as your offer is under the production cost. We would be willing to reconsider an offer of around 12-14 thousand pesos.
>
> Sincerely, The Japanese Delegates.

This message was followed by a response to the Japanese environmental delegates just 20 min later on the GE2 messaging system;

> Dear Japanese Delegates,
>
> We accept your offer however we are still finalizing the details. We shall purchase the 100 Bubble90's in exchange for 1,080 pesos. If these Bubble90's conserve an exceptional amount of water, we shall purchase more. We are open to future negotiations.
>
> Mexico's Environmentalists.

The messages above are a sample of over 2000+ similar messages sent among 19 social science classrooms of seventh- and eighth-grade students participating in a GE2 simulation focused on water resources. GE2 engages students in a combination of face-to-face and online web-based interactions as students in groups (generally social studies classes in schools) are assigned the role of delegates of a country to play in a 14-week simulation with the goals of each country-team reaching an agreement on the simulation topic with at least one other country in the simulation. Within each GE2 simulation, approximately 16–20 classrooms are recruited and assigned to represent the interests of specific countries. Each classroom of students is assigned one country to represent throughout the 14-week simulation period. The countries are carefully selected by GE2 staff to maintain diversity across economic development, geography, political structures, and centrality to the science issues being discussed in the simulation. This diversity provides an opportunity for students to experience global science issues from a wide variety of perspectives (i.e., geographic, economic, cultural, and political). Our simulations have focused on recruiting classrooms of students in grades seven and eight, because this is a period of formulation of concepts and understandings for students that impacts their future trajectory of learning strategies and self-efficacy. However, we have also conducted multiple simulations at the

Table 1 Sample list of typical countries in a GE2 simulation

Australia
Bangladesh
Brazil
China
Egypt
France
India
Indonesia
Iran
Japan
Mexico
Netherlands
Nigeria
Russia
Saudi Arabia
South Africa
Spain
Sudan
Turkey
USA[a]

[a] The USA is assigned to a special group of trained college students who are part of the GE2 staff, unbeknownst to the other teams

college level, and with educational professionals, as well as multiple simulations with high school social studies students (Table 1).

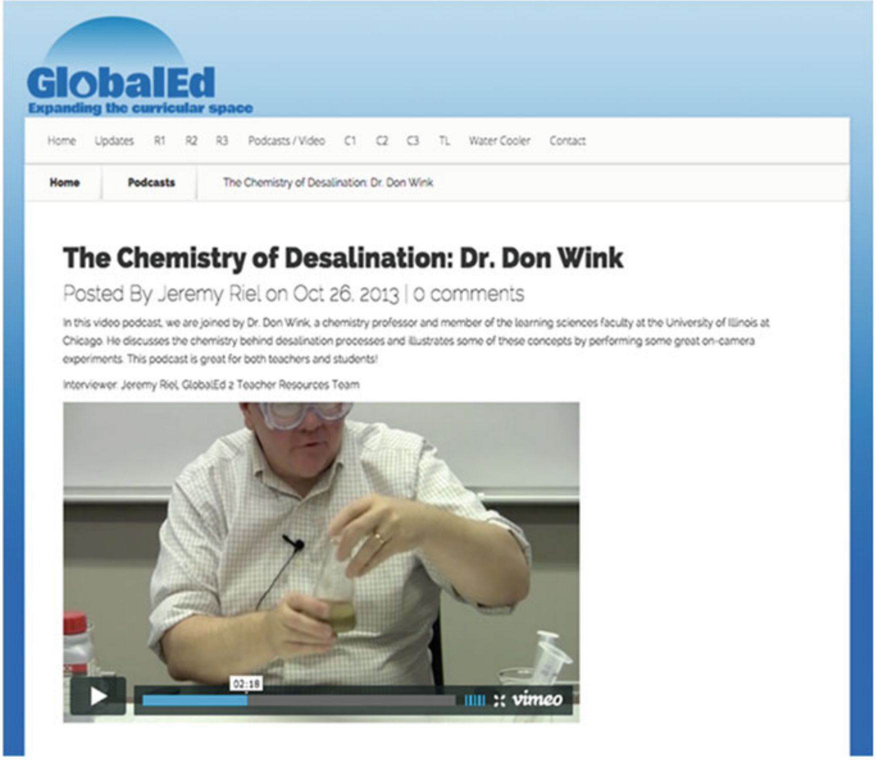
Each GE2 simulation is supported by a set of three important interdependent curricular components:

(a) The GE2 problem scenario, which sets the context and goals of the PBL, a descriptive text of approximately 15–20 pages written at the student's reading level for their grade.
(b) The GE2 simulation resources and materials for both students and teachers, documents and web-links to *The GlobalEd2 Student Resource Guide* and *The GlobalEd2 Teacher Guide*, and
(c) Four issue areas that are central within the simulation that further set the context of the problem space (Economics, the Environment, Health, and Human Rights).

The problem scenario is a document that provides background information about a current problem somewhere (or multiple places) in the world with specific scientific details that would lead the participating countries in the simulation to have to take timely action. It sets the common context for the countries in the simulation, anchoring interactions among students. The scenario details are scientifically accurate and present data about the situation in multiple formats (such as text, photos, video, tables, and charts) related to concerns the countries will be facing in the very near future. The GE2 problem scenario is specifically set 6 months into the future to minimize real-world social and scientific events that may occur during the GE2 simulation and potentially disrupt the students' problem-solving processes (i.e., wars, trade embargos, and natural disasters). The scenario is provided to the students participating in the simulation during the first phase of the simulation so that they can research their country's policies and positions, learn further about the science concepts associated with the scenario topic, prepare their positions, and plan a strategy for addressing the problem with a potential global partner.

The resources and materials for each simulation consist of real documents and summaries developed for the students, online sources, and websites pertaining directly to various aspects of the problem scenario, as well as country resources, available on the GE2 student website. For example, in the water resources scenario, materials report actual data on water consumption, pollution, irrigation, and access to fresh, clean potable water, as well as the issues currently facing each of the countries involved in the simulation. Students have also availed the opportunity to interact with experts from the community outside the classroom and simulation structure, through podcasts and interactive online sessions. These experts include environmental scientists, political scientists, government officials, and individuals who have first-hand knowledge of the countries represented within the simulation (see Fig. 1). Students use the resources in the online database in concert with their own prior knowledge and their understanding of the scenario as they begin to formulate a course of action and negotiation plan for the upcoming simulation. All resources and materials are accurate and actual documents, though scaffolds developed by the GE2 project team to increase middle school students' accessibility and comprehension, support many of these materials. This resource database is used recursively over the course of the entire simulation, as students refine and solidify their country's position and seek partners in the simulation.

There are four issue areas embedded within each simulation that address separate dimensions of the socio-scientific negotiations. These issue areas form the basis upon which a participating team breaks into smaller collaborative working groups to prepare for the simulation and to engage in the negotiations (as illustrated in Fig. 2). These four issue areas are consistent across all the classrooms in the simulation, enabling the students from one issue area to communicate with their counterparts in another classroom. For example, economics is one of the four issue areas consistent across all simulations. This issue area addresses the economic implications of the science policy being developed for their specific country. As a result, this issue group must focus on the cost and effect on their local economy of reducing pollution, opening access to fresh water to their neighbors, or entering into agreements with neighbors about accessing freshwater for their own citizens. The other three issue areas are Environment, Health, and Human Rights. It is important to note that the collaborative country-team work occurs both within the issue groups and across the entire country-team, but a country's proposed approach must address, and have the support of, all four issue area groups within their country. Therefore, although



The Chemistry of Desalination: Dr. Don Wink

Posted By Jeremy Riel on Oct 26, 2013 | 0 comments

In this video podcast, we are joined by Dr. Don Wink, a chemistry professor and member of the learning sciences faculty at the University of Illinois at Chicago. He discusses the chemistry behind desalination processes and illustrates some of these concepts by performing some great on-camera experiments. This podcast is great for both teachers and students!

Interviewer: Jeremy Riel, GlobalEd 2 Teacher Resources Team

Fig. 1 Sample resource from the students research and tools database for GE2

negotiations may take place between the specific issue groups across countries, it is necessary that these four issue groups are also negotiating within the country and come to consensus in representing the unified policy stance of the entire country to the other countries in the simulation.

There are three phases of the simulation lasting 14 weeks (see Fig. 3 illustrating the three phases of GE2). The first phase, the Research Phase, is 6 weeks in duration and requires the students to use text and web resources to research the simulation scenario issues. During this phase, students must identify the key scientific issues of concern, as well as how their assigned country's culture, political system, geography, and economy influence their perspectives. Additionally, students must also become familiar with the policies of the other countries included in the simulation, in order to develop initial arguments and plan for potential collaborations. As the outcome of the Research Phase, students in each classroom work collaboratively to develop an opening policy statement (written arguments) containing their national position across each of the four issue areas and how they wish to start addressing the international problem presented in the scenario with other countries who will also be negotiating within the simulation. These opening statements range in length

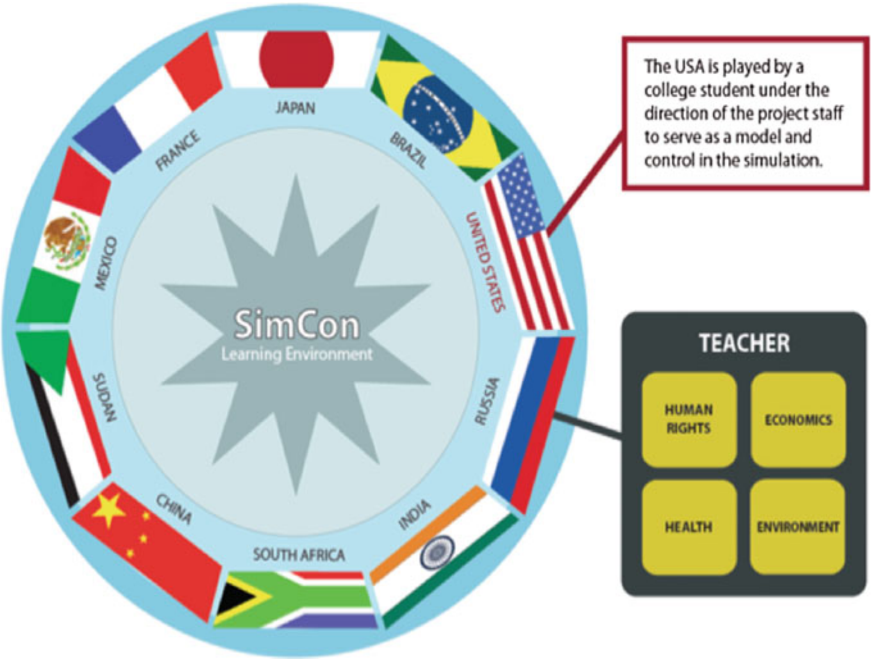
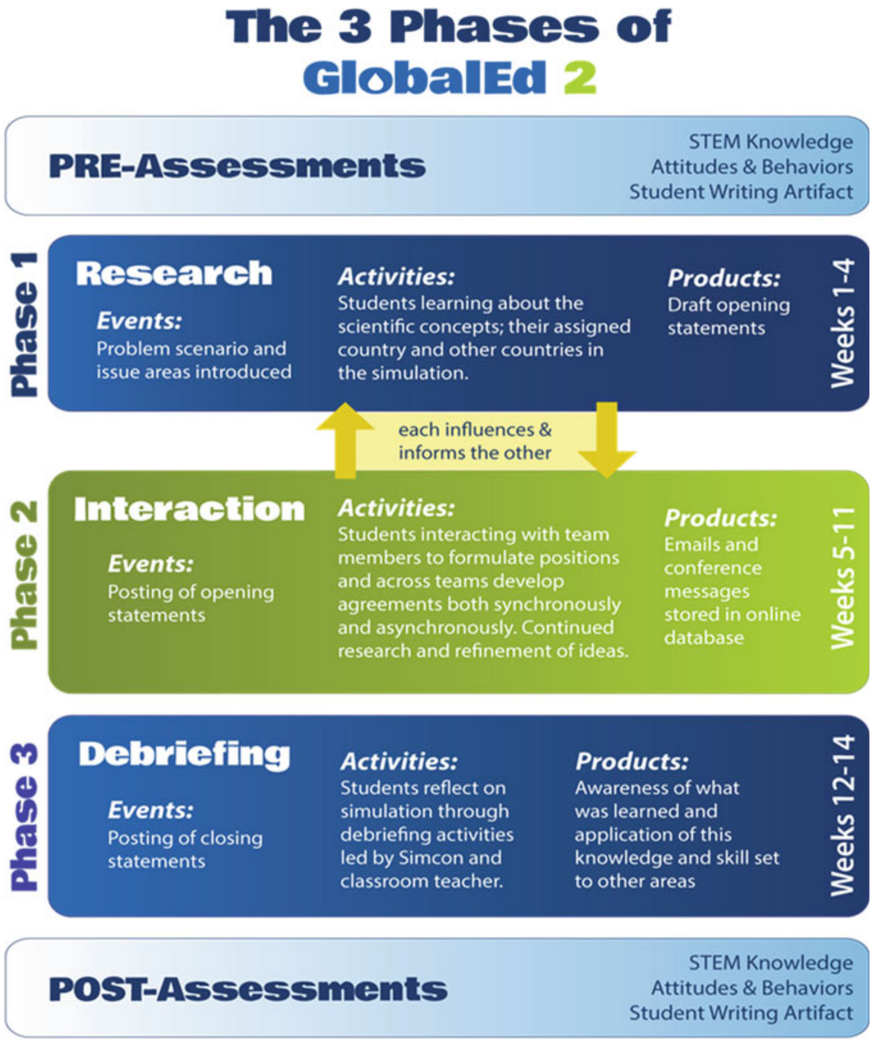


Fig. 2 The GE2 team environment

from 200–500 words, though some detailed statements may be longer. Final opening statements are shared as documents within the online GE2 communication system serving to launch Phase 2, the interactive negotiations across countries.

Throughout the 6 weeks of the Interactive Phase (Phase 2), students work within their class to refine their arguments and negotiate international agreements with the other "countries," sharing them online, in an asynchronous format similar to email. Based on prior implementations, the number of communications exchanged during the Interactive Phase can exceed 5000 (though length varies from a single sentence to longer multi-paragraph exchanges). Both the content and negotiations among the countries participating within this phase of the simulation are student-driven and dynamic, as the simulations are designed to engage participants in ill-structured and dynamic problem-solving (see Fig. 4). As such, while the larger context for the simulation is set by the problem scenario, what and how students negotiate emerges from their interactions with one another.

Students are also afforded the ability to engage in moderated synchronous conferences (instant messaging-like) at scheduled points throughout the Interactive Phase (see Fig. 5 for an abridged sample of a synchronous conference). These synchronous conferences are important for students in the same issue area groups across country teams to clarify understandings and push their written negotiations forward more quickly than is attainable through asynchronous communications. They also pro-



Events: Problem scenario and issue areas introduced

Activities: Students learning about the scientific concepts; their assigned country and other countries in the simulation.

Products: Draft opening statements

Events: Posting of opening statements

Activities: Students interacting with team members to formulate positions and across teams develop agreements both synchronously and asynchronously. Continued research and refinement of ideas.

Products: Emails and conference messages stored in online database

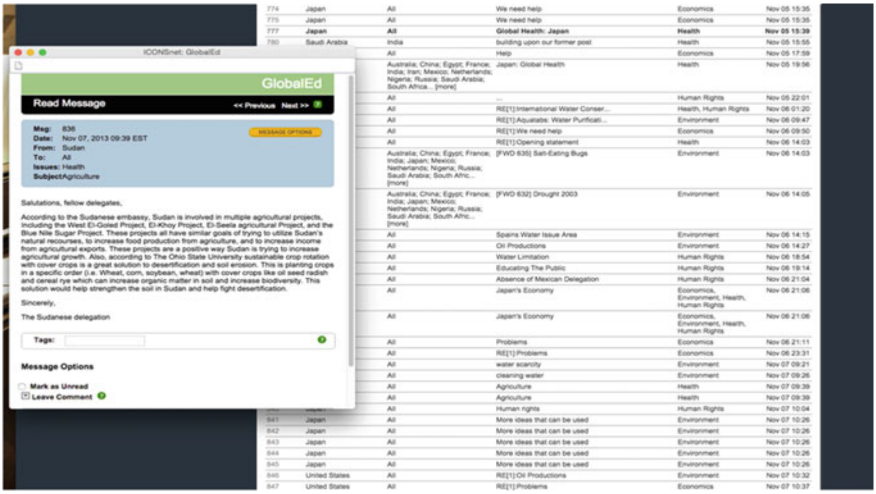
Events: Posting of closing statements

Activities: Students reflect on simulation through debriefing activities led by Simcon and classroom teacher.

Products: Awareness of what was learned and application of this knowledge and skill set to other areas

Fig. 3 The three phases of the GE2 simulation

vide significant practice in quickly formulating and communicating scientific arguments with real-time feedback. There are two scheduled synchronous conferences for each issue area, a total of eight per simulation. Each conference is scheduled for 60 min during the school day. Students work together as an issue area team, with 1–2 iPads/computers (note: GE2 provides 5 iPads per class) drafting and reading messages on separate devices. Conferences average 200–500+ messages ranging from 1–4 words of quick agreement, up to 50+ words of more of elaborate argumentation. Students are provided in advance with a series of 4–6 questions focused on the problem scenario (e.g., Human Rights related to *Water Resources*). The questions



Msg: 836
Date: Nov 07, 2013 09:39 EST
From: Sudan
To: All
Issues: Health
SubjectAgriculture

Salutations, fellow delegates,

According to the Sudanese embassy, Sudan is involved in multiple agricultural projects, including the West El-Goled Project, El-Khoy Project, El-Seela agricultural Project, and the Blue Nile Sugar Project. These projects all have similar goals of trying to utilize Sudan's natural recourses, to increase food production from agriculture, and to increase income from agricultural exports. These projects are a positive way Sudan is trying to increase agricultural growth. Also, according to The Ohio State University sustainable crop rotation with cover crops is a great solution to desertification and soil erosion. This is planting crops in a specific order (i.e. Wheat, corn, soybean, wheat) with cover crops like oil seed radish and cereal rye which can increase organic matter in soil and increase biodiversity. This solution would help strengthen the soil in Sudan and help fight desertification.

Sincerely,

The Sudanese delegation

Tags:

Message Options

☐ Mark as Unread
⊞ Leave Comment

774	Japan	All	We need help	Economics	Nov 05 15:35
775	Japan	All	We need help	Economics	Nov 05 15:35
777	**Japan**	**All**	**Global Health: Japan**	**Health**	**Nov 05 15:39**
780	Saudi Arabia	India	building upon our former post	Health	Nov 05 15:55
		All	Help	Economics	Nov 05 17:59
		Australia; China; Egypt; France; India; Iran; Mexico; Netherlands; Nigeria; Russia; Saudi Arabia; South Africa... [more]	Japan: Global Health	Health	Nov 05 19:56
		All	...	Human Rights	Nov 05 22:01
		All	RE[1]:International Water Conser...	Health, Human Rights	Nov 06 01:20
		All	RE[1]:Aquatabs: Water Purificati...	Environment	Nov 06 09:47
		All	RE[1]:We need help	Economics	Nov 06 09:50
		All	RE[1]:Opening statement	Health	Nov 06 14:03
		Australia; China; Egypt; France; India; Japan; Mexico; Netherlands; Nigeria; Russia; Saudi Arabia; South Afric... [more]	[FWD 635] Salt-Eating Bugs	Environment	Nov 06 14:03
		Australia; China; Egypt; France; India; Japan; Mexico; Netherlands; Nigeria; Russia; Saudi Arabia; South Afric... [more]	[FWD 632] Drought 2003	Environment	Nov 06 14:05
		All	Spains Water Issue Area	Environment	Nov 06 14:15
		All	Oil Productions	Environment	Nov 06 14:27
		All	Water Limitation	Human Rights	Nov 06 18:54
		All	Educating The Public	Human Rights	Nov 06 19:14
		All	Absence of Mexican Delegation	Human Rights	Nov 06 21:04
		All	Japan's Economy	Economics, Environment, Health, Human Rights	Nov 06 21:06
		All	Japan's Economy	Economics, Environment, Health, Human Rights	Nov 06 21:06
		All	Problems	Economics	Nov 06 21:11
		All	RE[1]:Problems	Economics	Nov 06 23:31
		All	water scarcity	Environment	Nov 07 09:21
		All	cleaning water	Environment	Nov 07 09:26
		All	Agriculture	Health	Nov 07 09:39
		All	Agriculture	Health	Nov 07 09:39
		All	Human rights	Human Rights	Nov 07 10:04
841	Japan	All	More ideas that can be used	Environment	Nov 07 10:26
842	Japan	All	More ideas that can be used	Environment	Nov 07 10:26
843	Japan	All	More ideas that can be used	Environment	Nov 07 10:26
844	Japan	All	More ideas that can be used	Environment	Nov 07 10:26
845	Japan	All	More ideas that can be used	Environment	Nov 07 10:26
846	United States	All	RE[1]:Oil Productions	Environment	Nov 07 10:32
847	United States	All	RE[1]:Problems	Economics	Nov 07 10:37

Fig. 4 A sample of a simulation asynchronous message within the GE2 communication platform

allow for segmenting the conferences into 10 min intervals. This segmented structure is designed to enable student-teams to enter and leave a conference as school schedules allow when implementing GE2 across multiple school districts that do not share common class period systems. Students participate in GE2 conferences outside of their scheduled GE2 class (in the library, study hall, other classes, and even hallways).

In order to provide some control and flow in this phase, a trained simulation coordinator, "SimCon," monitors the flow of e-messages between teams and also facilitates scheduled "real-time" web-based multilateral conferences through an instant messaging-like interface in GE2. SimCon's role is similar to that of a virtual facilitator in an active learning classroom, in which SimCon oversees all aspects of the learning process and also coaches students to think critically about the complex issues central to their arguments. Further, SimCon monitors and provides feedback to students regarding the content (political and scientific), argument structure, and tone of their communications with other countries as a means of formative evaluation on a weekly basis. In past simulation, participating students have often modeled SimCon's strategies, providing these evaluative cues to each other, resulting in a positive peer feedback system.

The culminating event of the 6-week Interactive Phase is the posting of each country's closing statement, reflecting the final position of each country-team on each of the four issue areas. Students work collaboratively within their country-team issue area to construct these closing arguments, articulating points of agreement, and topics where continued work is necessary among the participating countries. These closing arguments are then shared with the other participants in the simulation, marking the start of the third phase of the GE2 experience, Debriefing.

41 **Turkey**: #2 The Turkish Delegation believes that water is a priority for many different reasons but drinking water is the most important. Without drinking water we would not be able to live longer than a week. Although clean clothes and clean dishes are important, humans can survive without them. So we believe that in the right to water, it should specify what the water should be used for. Turkey believes it should be used for drinking first, because that would be the most important, and then if there is extra, it can be used for washing clothes cleaning dishes, and taking showers.

42 **France**: 2.France believes that it is better to have water for bathing than for drinking because the average French person uses about 40% of their water for bathing and only about 1% of their water for drinking. Also if you bathe in dirty water you can get many diseases.

44 **United States**: The US believes that drinking water is more important than religious and cultural purposes, but that drinking and hygenic-purpose water are both equally important

45 **Russia**: The right to water indicates that there needs to be a sufficient amount of water for personal and domestic use. Clean drinking water, without a doubt is more important than clean water for bathing and other hygienic purposes; laundering and washing dishes and/or for religious or cultural purposes.

46 **Russia**: U.S, would you be willing to contribute to countries in need of water? And so, how much?

47 **United States**: Russia 46: While the US is willing to help countries, giving water to others must be balanced by several factors. First, we would need to receive something in return. Water is a valuable national resource. Second, we would want a monitoring program in place by the international community to make sure our water is being used properly

48 **Mexico**: Drinking water is the most important human right people are entitled to. Showering and cleaning is a close second water related human right because if we are unsanitary, disease will engulf us and water problems will only spread. Religion also takes important precedence because we can't keep people from practicing their religion.

49 **China**: If countries that use lots of water for luxuries and they held back the usage amount for countries with less water we could definatley halve the amount of people that don't have access to clean drinking water by 2015. Also lots of people do this but make sure when you leave a place with a sink or faucet or bathtub make sure the water is shut off.

51 **China**: Turkey 32: Obviously water for drinking is important, but what would you consider as a luxury? Would that include washing cars of taking a shower?

52 **Turkey**: United States 37: If a plan for rotation of responsibility of countries to supply water to countries who need it was put in to action, it would also create inspections for countries who recieve water. Those who perform the inspection would create the report. The report would summarize who recieved the water, what areas of the country recieved the water, and how water was transported to those people.

53 **South Africa (byoung)**: We believe, that both are important. We believe that we shouldn't completely limit off water for certain uses. We do not believe that people should not be able to practice their religion because of water. People should be able to do as they wish with their faith. We also believe that we could reuse water. For example, water you do not use in the bath tub or shower, could wash into your toilet. We think it is a necessity to launder and clean with fresh, new water because disease and sickness can be transfered through unsanitary water.

Fig. 5 An abridged sample of a synchronous conference within the GE2 simulation phase 2

The Debriefing Phase lasts 2 weeks and is designed to activate metacognitive processes in students, as they review what they learned and how they can apply this new science content knowledge and associated skills in other contexts and domains. SimCon facilitates a scheduled online debriefing conference with all countries represented in the simulation, exploring issues related to learning outcomes, simulation processes, transfer of skills to other contexts—both in and out of school, and feedback. Teachers are also trained during the professional development process to perform multiple debriefing activities within their classrooms to promote metacognition, learning, and transfer. These include educational activities, such as analyzing the “behind-the-scenes” negotiations available to students after the simulation ends (reviewing transcriptions of online for patterns and missed opportunities), writing final essays about the experience, examining local water resource issues, or completing other tasks aimed at relating the experience back to the educational context and the real world of environmental sustainability in both local and global affairs.

It is extremely important to note, all interactions in GE2 are text based—a purposive GE2 design principle for two reasons. First, the written artifacts which the students produce (e.g., opening/closing statements and online negotiations) are a means of making students’ thinking visible on a consistent basis, providing an avenue for teachers, and researchers to formatively assess students’ engagement, critical thinking, writing, leadership, and problem-solving. GE2 teachers are trained in the use of these written interactions as an evaluative tool during their professional development (PD) prior to starting the GE2 simulation with students and are provided assessment rubrics in the GE2 curricular materials to facilitate this process. Second, the use of this anonymous written communication mode allows educators to hold some factors in the GE2 educational context-neutral (e.g., personal appearance, gender, race, verbal communication abilities, and accents). Students only identify themselves within GE2 as country, issue, and initials, for example, “swbChinaenv” (China’s environmental negotiator s), blinding their actual identities to students outside their classroom. As a result, typical stereotypes, often associated with gender, race, or socioeconomic class, are minimized as factors influencing the interactions among participants (Picho & Brown, 2011; Steele, 1997).

2.1 The Role of Technology in GE2

Technology plays a critically central role in enabling and enhancing the objectives of GE2. Producing a global decision-making environment like GE2 is not logistically possible within a single school location due to: (a) the numbers of classrooms required to reach a critical mass of active engagement (14–18 classes of similar grades); (b) access to the necessary technologies on this scale; and (c) the needs of teacher supervision for the large number of GE2 students (~ 350–500). The technology use in GE2 is transparent with the technology serving as tool used by students to conduct research on the countries engaged in the simulation, the simulation topic, and related socio-scientific issues, and as a communications tool in Phase 2 and 3 providing the basis for cross-team interactions in by asynchronous and synchronous formats. GE2 technology is used to address the four themes of twenty-first-century skills identified at the beginning of this chapter: Problem-solving, Collaboration and Teamwork, Critical Thinking, and Creativity.

The web-based communication and research platform used by GE2 provides a systematic opportunity for students working in groups across diverse geographic locations to communicate with and learn from, one another in the simulated global environment. In addition, because GE2 leverages the current cyber infrastructure available to most schools and community settings (devices connected to the Internet), participants will have ready access to the enabling technologies and are not required to have, or procure, new and expensive technologies to participate. The simulation and associated curriculum materials are accessible via any device that can host a web browser, including netbooks, iPads and tablets, and smartphones—providing access to the simulation almost anywhere, on any device, at any time.

Further, the Oracle-based simulation software that serves as the backbone of the GE2 communications, archives (e.g., by date, subject, sender, and recipient) all of the messages (asynchronous and synchronous) during the interactive simulation period. As a result, students (and teachers) are able to access older discussion threads during the course of the simulation (though they can only access those that they have sent or received while the simulation is ongoing). Such "historical" access is often needed to track consistency in the positions taken by countries in the online negotiations. Teachers are also able to track their own students' work in this way during the simulation. After the simulation is over, the simulation community is opened to all participating teachers and students, allowing access to all messages sent and received regardless of sender or recipient providing messages, that are date- and time-stamped, for review and analyses by teams as they learn to improve their science literacies, social perspective-taking, writing skills, and develop as global citizens. This provides students and teachers with a wealth of data to examine, reflect upon, and write about. Further, this data provides a treasure trove for researcher examining similar themes and the key components of a successful simulation.

3 GE2 Teacher Professional Development Training

As we have discussed previously in our work on GE2 professional development for teachers, (Riel, Lawless, & Brown, 2016, 2017, 2018), the key to successful implementation of GE2 is a cadre of well-trained professional educators. GE2 teachers receive Professional Development training (PD) through the GE2 PD web portal (see Figs. 6 and 7), providing an array of resources and instructional support materials for teachers as they prepare to learn about the pedagogy of PBL, the structure, and process of GE2, and the interactive web component during phase 2, based on what the literature tells us about the implementation of effective PD (Lawless & Pellegrino, 2007). Teachers also have access to a web portal of teacher and student resources that may be used to support GE2 activities during the simulation, such as lesson plans, student activities, rubrics, and resources, that are teacher-developed and teacher-tested by current and former GE2 teachers. Finally, as the last phase of the GE2 PD, the teachers participate in a mini-GE2 training simulation (6 h) taking on the role of students, so that the teachers can experience GE2 from the perspective both roles: Teachers and Students. In this way, the teachers are well prepared to guide the students in the PBL environment, having had an experience working through each of the three phases, using the communications system and balancing the four issue area demands while immersed in a shorter controlled GE2 training simulation. We have found teachers consistently reporting the mini-sim experience

Simulation Newsletter – Issue 13
December 15, 2014
Here is this week's simulation newsletter for students. More →

Simulation Newsletter – Issue 12
December 4, 2014
Here is this week's Simulation Newsletter (issue 12) More →

Water Article Roundup – 12-04-2014
December 4, 2014
Here is a collection of articles from around the web this week on issues related to water pollution, water quality, clean water and water stress More →

Water Article Roundup – 11-20-2014
November 20, 2014

Simcon Debriefing Conference: Goals and Outcomes
December 3, 2014
Nicole Powell, a former Simcon, discusses the debriefing phase and what students should attend to during the debriefing conferences with Simcon. More →

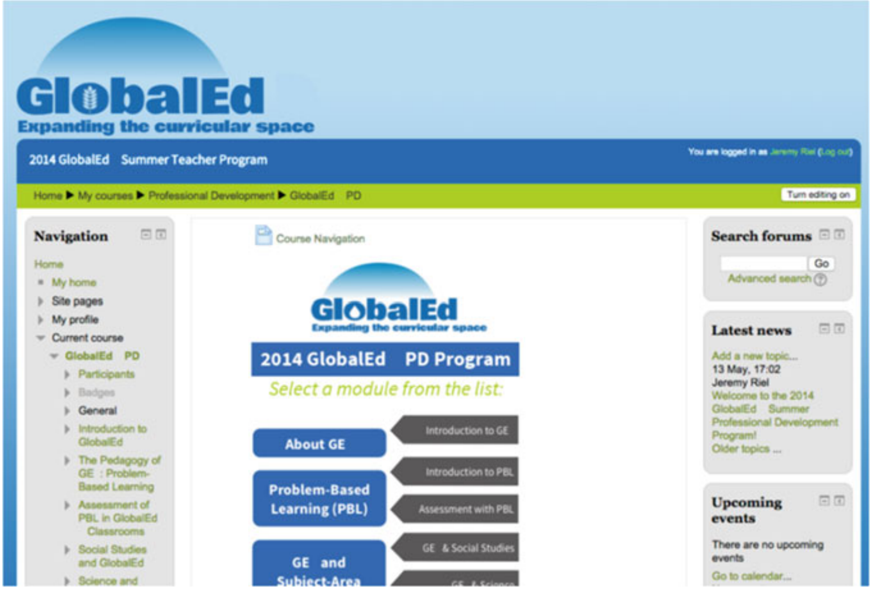
Phase 3 of GE2: Overview & Teaching Tips

Fig. 6 A screenshot of the opening GE2 webpage for teachers

as one of the most valuable PD components in preparing them to implement GE2 in their own classrooms in the moths that follow.

Teachers implementing GE2 are supported by both front-end and ongoing PD provided through an online *Instructor Portal*. Prior to implementing GE2 in their classrooms, teachers complete a total of approximately 24 h of online instruction (instruction is structured into separate content/skill modules) in which they learn about GE2, the theory behind it, how teaching and assessment occurs within GE2, how to support students to write effectively and the science and social science content needed to successfully implement GE2 with students.

Ongoing PD continues over the course of the implementation, using a “just-in-time” training model through weekly podcasts providing content and process suggestions to teachers as demanded by the trajectory of the students’ interactions in the simulation (Riel et al., 2017). Finally, an online community of practice among the



You are logged in as Jeremy Riel (Log out)

Select a module from the list:

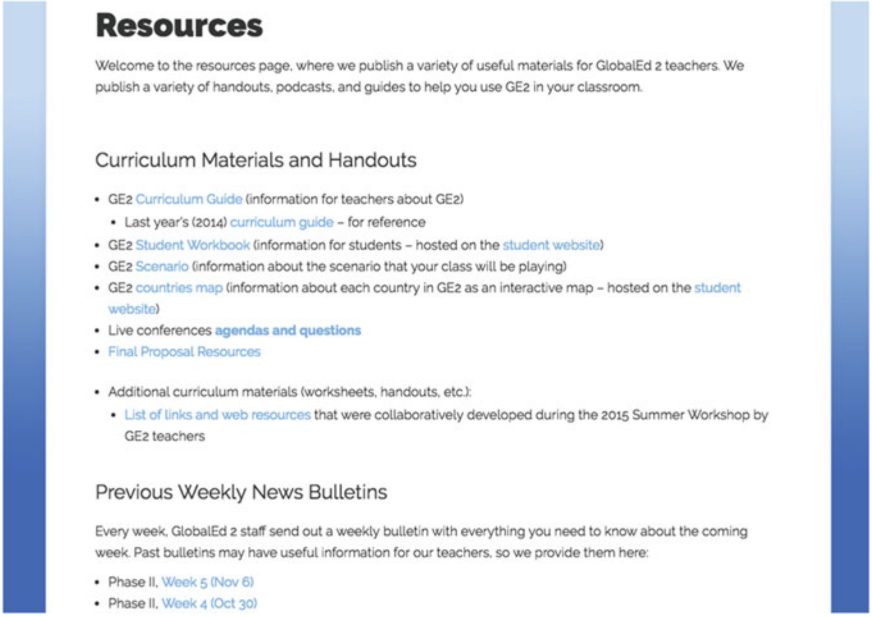
13 May, 17:02
Jeremy Riel
Welcome to the 2014 GlobalEd Summer Professional Development Program!

There are no upcoming events

Fig. 7 Screenshot of the GE2 instructor web portal

teachers across sites and the GE2 staff serves as a forum for exchanging information, asking questions of each other and GE2 staff, and collaboratively developing new knowledge, procedures, and resources for future GE2 implementations.

The *Instructor Portal* also provides access to an array of GE2 instructional supports and learning scaffolds. The materials provided on the *Instructor Portal* were specifically designed to help students to identify and align important information across disciplines that impinge upon the problem space. Understanding the world water crisis, for example, requires that students understand the earth's water purification cycle (hydrologic cycle), economic implications of water trade, water as a "virtual" commodity, access to water as a human right, and health issue and water reclamation technologies (see Fig. 8 for a sample). In addition to content, instructional materials are available to help support the quality of students' written scientific argumentation using the three chain links of **Claim→Evidence→Reasoning** (CER), which may appear in various orders (McNeill & Krajcik, 2008; Toulmin, 1958). Finally, worked examples and evaluation rubrics are provided to GE2 teachers in support of their assessment of student learning, both formatively and summatively.



Resources

Welcome to the resources page, where we publish a variety of useful materials for GlobalEd 2 teachers. We publish a variety of handouts, podcasts, and guides to help you use GE2 in your classroom.

Curriculum Materials and Handouts

- GE2 Curriculum Guide (information for teachers about GE2)
  - Last year's (2014) curriculum guide – for reference
- GE2 Student Workbook (information for students – hosted on the student website)
- GE2 Scenario (information about the scenario that your class will be playing)
- GE2 countries map (information about each country in GE2 as an interactive map – hosted on the student website)
- Live conferences **agendas and questions**
- Final Proposal Resources

- Additional curriculum materials (worksheets, handouts, etc.):
  - List of links and web resources that were collaboratively developed during the 2015 Summer Workshop by GE2 teachers

Previous Weekly News Bulletins

Every week, GlobalEd 2 staff send out a weekly bulletin with everything you need to know about the coming week. Past bulletins may have useful information for our teachers, so we provide them here:

- Phase II, Week 5 (Nov 6)
- Phase II, Week 4 (Oct 30)

Fig. 8 A screenshot of the GE2 science support page for teachers

3.1 *Why Was GE2 Created?*

Our current age of globalization has spawned a wide spectrum of issues, encompassing both the expected and unexpected. Almost daily, we are confronted in the media and in our personal interactions, with accounts of how globalization affects our lives through international conflicts, changes in oil or coffee prices, and natural disasters that affect thousands and sometimes millions of people on the other side of the world, or the local people right in our own neighborhood. We are also confronted with substantial evidence indicating that these changes are not benign and that many actors are actively working to manipulate, or at least control, the effects of globalization at the global, national, local, and individual level. Put simply, one of the major themes of life in the new millennium is that global meets the local, or what has become known as "*glocal*" (simultaneously representing both global and local issues), necessitating the development of *global citizens*.

All the evidence about globalization, particularly as it relates to the individual-level effects, raises concerns about how the next generation of citizens, leaders, and policy-makers—the students sitting in our schools today—perceive and interact with the world around all of us. From our daily experience as parents, teachers, researchers, community members, and national leaders, we can provide answers to this question based on anecdotal data and intuition, and we have many stories to tell about the "globalism" of our children. We take lessons from our children on how to use technology effectively, where to find things on the Internet, and especially in the twenty-first-century world, we hear them talking about international affairs casually, but in very sophisticated ways. Today's students talk about issues around the world that were not part of conversations only 20 years earlier. The media and the Internet have influenced our perceptions of our social world so that we see and learn about conflict and natural disasters in real time, on the web, and on our phones.

The need for students to learn about global issues within a safe instructional environment that also allows the students to role play in this new simulation without concerns of appearance, language, or stereo-typing (see Picho & Brown, 2011; Steele, 1997). We created GE2 to be that safe educational environment where students could play a new role for many of them, as a science delegate representing a real country somewhere around the globe. Further, for a period of 14 weeks, these country teams were to work together to solve the problem presented n the scenario with at least one other country—not necessarily all 20 countries. In other words, to make progress on socio-scientific issues affecting the world we live in. The interactions between teams of students occurred in a supervised context that both provided structure and consistency, and also allowed students to be creative in solving the problems presented in the scenario from multiple perspectives. In this way, no two simulations are identical in how they are conducted, how the countries interact, or the solutions are proposed and acted upon.

Our students today are regularly linked students in other states, and other countries, through e-exchange programs and, more simply, through Internet interactions and/or satellite/Wi-Fi video access in classrooms. Clearly, our students have unprecedented access to a wealth of information about the world around us. The availability and possibility of global interaction for our children through the Internet and other resources, in turn, raise important questions for parents, educators, policy-makers, and researchers to grapple with, as we work to socialize and educate our children so that they are prepared to participate and lead in a globally complex society. This presents a unique opportunity and a corresponding host of challenges to educational psychologists today—How to develop learning environments for students that will promote knowledge, attitudes, and behaviors (KABs; Schrader & Lawless, 2004) that will enable these students to learn and to grow into productive citizens locally, nationally, and globally? The KABs provide us the mechanism to assess in what students know (Knowledge), what students feel about things (Attitudes), and how students act/perform (Behaviors) so that we may measure the impact of the GE2 curriculum on student learning across these three dimensions.

3.2 GE2's Underlying Theory of Change

The GE2 simulation is built upon Albert Bandura's framework of Reciprocal Determinism (Bandura, 1986) which can explain educational change in a wide variety of educational interventions, specifically focused on STEM topics. Within this framework, students are neither singularly driven by inner forces nor automatically shaped and controlled by external stimuli. Rather, learning is explained in terms of a model of triadic reciprocity, in which behaviors, personal factors, and environmental events all operate as interrelated mutual determinants of each other (Pajares, 1996). Research has shown that effecting positive change in this type of systemic model of learning requires changes across all three interacting elements and multiple domains (Zimmerman, 1989).

From this perspective, to increase science achievement and civic engagement in order to reach the ultimate goal of a globally literate citizenry, we must develop and rigorously test new science educational interventions within our schools that nurture and promote students' Knowledge, Attitudes, and Behaviors through the implementation of pedagogical approaches that integrate an authentic, interdisciplinary rationale for the importance and personal relevance of the content students are learning.

The PBL environment enacted in GE2 directly impacts student learning outcomes related to KABs in each of the three GE2 focal domains: (1) Science and civics, (2) Written argumentation, and (3) Interest related to science and the pursuit of future science-related endeavors. Further, we purport that participation in GE2 will also impact distal student outcomes specifically related to scientific literacy and global citizenship. Finally, because previous findings suggest a differential impact of the curricular intervention in favor of females and urban students (Brown et al., 2015; Lawless & Brown, 2015; Lawless et al., 2017), we posit that the evidence supports GE2 as an effective educational model that can be leveraged to promote reductions in the documented achievement gaps among existing groups of students.

3.3 How GE2, a Social Studies Curriculum, Addresses Socio-scientific Literacy Instruction

The scientific and academic community has been sounding the warning alarm about the crisis in education for years: Our schools are not producing the STEM professionals necessary for the US to maintain its scientific and technological prominence, thereby putting our future global standing at risk. Beyond the need for more highly trained professionals within STEM fields, however, we argue that we also face a much larger societal crisis—The need to establish a globally literate citizenry who are prepared to understand and participate in a global arena. Rapid economic, technological, political, and social changes are generating a world that is increasingly more interconnected and interdependent. Globalization of economies, the proliferation of technology, mass immigration, and the prospect of climate and food instability are but three of the many factors shifting the necessary skill sets necessary to become a competent citizen in the twenty-first century (Mansilla, Jackson, & Jacobs, 2013). In addition to skills abilities afforded by the traditional domains of literacy, math, and science, it is imperative that contemporary citizens develop an understanding of economics, security, cultural identity, citizenship, health, and the environment. To be successful in the globalized world, citizens must also be sensitive to and fluent with diverse perspectives, be able to communicate across cultures, and be prepared to act toward the common good (Zhao, 2009).

Advocates argue that science instruction should be inquiry based and centered in perennial issues of societal concern, particularly issues of socio-scientific concern (Barton & Levstik, 2004; Rose & Barton, 2012; Sadler, Romine, & Topçu, 2016). Socio-scientific contexts, such as GE2, afford students the opportunity to ground their learning in the world in which students currently live, making both social studies and science personally relevant (Anderson, 2002; NRC, 1996; Sadler, 2009). Socio-scientific issues are complex and often do not have a single clear-cut solution. Such issues confront students with situations in which they have to engage in formulating positions based on data, their own experiences and values, and collaborative decision-making. They are regarded as real-world problems that can afford the opportunity for students to participate in the negotiation and development of meaning through argumentation, promoting epistemic, cognitive, and social goals, as well as enhancing students' understanding of society and science (Chinn & Malhotra, 2002; Osborne, Erduran, & Simon, 2004; Schwartz, Neuman, Gil, & Ilya, 2003). Further, they help students make sense of the coupling of human and natural systems (Scheiner & Willig, 2008).

We know that socio-scientific literacies are composed of more than just content knowledge. Socio-scientific literacies require an understanding of the representation and interpretation of scientific evidence, scientific explanations and projections, and the basic processes of science, as well as the importance of the social context. Further, socio-scientific literacy involves cognitive and metacognitive abilities, collaborative teamwork, effective use of technology, and the communication skills to engage in discourse around global issues, synthesize disparate concepts, and persuade others to take informed action based on data and evidence (Hand, Yore, Jagger, & Prain, 2010; Hurd, 1998). These skills parallel those employed in the authentic work of twenty-first-century scientists (Chinn & Malhotra, 2002; Newcombe et al., 2009; Schwartz, Lederman, & Crawford, 2004). Contemporary scientists bring their knowledge, insights, and analytical skills to bear on matters of public importance. Often they can help the public and its community leaders understand the likely causes of events and estimate the possible effects of projected policies (such as the ecological impacts of various water conservation methods). In playing this advisory role, scientists are expected to be especially careful in distinguishing fact from interpretation, and research findings from speculation, opinion, and bias (Millar & Osborne, 1998; Monk & Osborne, 1997), as are the citizens who are consuming this information to develop their own positions—the essence of a scientifically literate citizen (NRC, 2011).

In step with these perspectives on the importance of a scientifically literate society, science standards over time have evolved from a solitary focus on content to a practices and processes orientation. The Next Generation Science Standards (NGSS), for example, have placed an added emphasis on crosscutting ideas that help students understand the relevance of science in their own lives and everyday world focuses on problem-solving and the communication of science across audiences

(NGSS, 2013). With these guiding principles, NGSS steers instruction away from traditional cognitively oriented instructional approaches, where knowledge is transferred from a teacher or a textbook to the learner. Instead, the new standards push toward student-centered, inquiry-based pedagogies that are much more rooted in a sociocultural perspective on learning (NRC, 2011). From a sociocultural orientation, learning takes place as individuals participate in the practices of a community, using the tools, language, and other cultural artifacts of the community. From this perspective, learning is "situated" within, and emerges from, the practices in different settings and communities (Lave & Wenger, 1991; Wenger, 1998).

The GE2 simulation presents an experience whereby students may engage in authentic, "real-world" socio-scientific problems that require action at an international level to resolve, if it is indeed, possible, within a challenging but safe educational environment. GE2 has over 10+ years of experience in providing innovative international simulations to more than 10,000 students from middle school through college and with educational professionals, across the USA and three other countries (Brown, 2007; Brown, Lawless, & Boyer, 2013; Brown et al., 2015; Lawless & Brown, 2015, in press; Lawless, Brown, & Boyer, 2016).

3.4 Problem-Based Learning (PBL) and the GE2 Simulation

Problem-based learning (PBL) researchers have demonstrated that leveraging interdisciplinary contexts to engage in real-world problem-solving can deepen students' understanding and flexibility in the application and transfer of knowledge (Bednar, Cunningham, Duffy, & Perry, 1992; Brown, Lawless, & Boyer, 2009; Brown et al., 2015; Koschmann, Kelson, Feltovich, & Barrows, 1996). GE2 is a set of socio-scientific simulations that capitalize on the multidisciplinary nature of social studies as an expanded curricular space to engage middle school students with science-based content. Making use of an Oracle-based Internet communications system and a simulation-specific, web-based research environment, GE2 links classrooms of students, otherwise, isolated from one another by physical distance and socioeconomic boundaries, in asynchronous (email-like) and synchronous communication (e.g., chat room, instant messaging format).

The simulations for GE2 are based on the six PBL principles and design components of Goodnough and Hung (2008), Jonassen (2009), Koschmann et al. (1996), Savery and Duffy (1996), and Greening (1998), which stated that the PBL environment must

- Anchor the learning activities to the larger task or problem presented in the situation;
- Support the learners in developing ownership and control over the problem;
- Be based on authentic, real-world, global problems;
- Be challenging;
- Provide alternative views and solutions; and
- Require the students to reflect on both the content and the process.

In addition to the six PBL principles presented above, there is a 2 × 2 set of dimensions along which a PBL environment may be created: Level of Stability (Static or Dynamic) and Level of Structure (Well-structured or Ill-structured). A well-designed PBL includes six principles listed in the bullets previously and may be built to exist across these two dimensions. For example, the PBL scenario which sets the problem in a context may be static (unchanging/consistent) and well-structured (parameters/limitations are clearly stated), as in problems that challenge the students to plan a rescue mission for someone injured in the woods, providing only a list of specific options and parameters—time, food, type of injury, distance to be covered, and modes of transportation. Or the PBL scenario may be dynamic (changing) and ill-structured (the parameters/limitations are not clear and may change based on decisions and actions during the solution process), such as problems that challenge students to deal with a global epidemic and how organizations within and across nations may deal with containment, diagnosis, treatment, and/or inoculation. The second example is going to be strongly influenced by the countries impacted, the resources available, the culture, geography, and type of disease, so that the same problem may be addressed in 10 different ways (or more) across 10 different solution teams, depending on their understanding of the context within the country they are representing.

Our current GE2 library of scenarios and support materials are focused on the following three topics:

1. Water Resources;
2. Food Security; and
3. Climate Change.

All three scenarios vary in approach to and the resulting resolutions, based on the countries the groups of students are assigned to play over the GE2 intervention period of 14 weeks.

GE2 is an educational simulation that uses PBL as the foundation to build upon the interdisciplinary nature of social science as an expanded curricular space designed to increase instructional activities devoted to the development of global citizenship, science literacy issues, and written argumentation in a simulation of international negotiations (Brown et al., 2013; Lawless & Brown, 2015).

3.5 Findings from GE2 Simulations

To date, various iterations of GE2 have been implemented in urban and suburban social studies classrooms for the better part of the last two decades. In the section below, we provide evidence of impact on critical proximal and distal outcomes (see Brown, Lawless, Rhoads, Newton, & Lynn, 2016; Lawless & Brown, 2015; Yukhymenko, 2011 for extended discussion and supplemental findings).

The first several years of research and development targeted the implementation of GE2 with high school social studies students. The focal outcomes for these implementations included students' Knowledge about geography, global governance, and international relations, Attitudes regarding their interest and self-efficacy with respect to social studies, and Behaviors related to social perspective-taking, leadership, negotiation, and civic engagement (KABs). Using a pre-experimental, pre-post design, results across several independent studies indicated statistically significant gains in global knowledge related to the scenario topic, heightened self-efficacy and attitudes about global governance as well as pro-social increases in behaviors related to social perspective-taking (Boyer et al., 2004, 2009; Gehlbach et al., 2008). Further, significant gender differences in KABs associated with negotiation and leadership styles were identified, in which males presented negotiation styles that were more often categorized as conflictual and focused on self-interest, than females—even when all students were blind to the gender of their counterparts online (Brown et al., 2003; Florea et al., 2003). An independent meta-analysis examining quantitative data emerging from multiple pre-experimental studies of GE2 found average effect sizes for outcomes to be between 0.19 and 0.31 for samples of high school participants (Yukhymenko, 2011).

Following the work with high school students, a revised version of the simulations, GE2, was developed and piloted with middle school students and subsequently subjected to efficacy trials. In total, GE2 has serviced >7000 students and their respective social studies teachers. As reported by (Brown et al., 2013, 2015; Lawless & Brown, 2015; Lawless et al., 2016) prior to, and immediately after engaging in GE2, students in each of our studies responded to a battery of assessments. Students in comparison groups also completed the same assessments, but only participated in normal education practice (NEP) within their social studies classrooms. The main assessment is a writing prompt patterned after those collected on standardized tests of persuasive writing. This written measure of argumentation required students to respond individually to a prompt (e.g., "The world is in danger of running out of fresh water. Do you agree or disagree with this statement? Why?"). Instructions directed students to use scientific evidence and reasoning to support their responses. Students' responses were evaluated for quality of argument, including **C**laim–**E**vidence–**R**easoning chains, using a modified version of the writing scale rubric developed by Midgette, Haria, and MacArthur (2008).

Empirical findings from pilot and efficacy work indicate significant positive outcomes for written scientific argumentation with moderate to strong effects ($d = 0.3$–0.43, assuming 15% treatment contamination from teachers serving as their own control). Small positive effects were also found for writing self-efficacy, converging around an effect size of 0.20 (Brown et al., 2013, 2015; Lawless & Brown, 2015; Lawless et al., 2016, 2017).

We also assessed knowledge gains in science related to the simulation scenario topics. Students were administered short multiple-choice tests on either water resources or climate change in pre- and post-format. Small effect sizes indicating positive change were noted ($d = 0.15$). While these effects were smaller than we had anticipated, it should be noted that the measure of knowledge implemented was short (18 items) and was potentially inadequate for sampling the full range of content and showed less than optimal reliability of scores (alpha = 0.65). Based on the prior efficacy data, the knowledge measure will be revised as part of future investigations.

With respect to distal outcomes, positive gains were noted for Socio-Scientific Literacy (SSL) and Science Inquiry (SI). From one 14-week experience within GE2, students in the treatment groups outperformed students in the NEP group on both of these measures (d = 0.15 and 0.23 assuming 15% treatment contamination). Other positive outcomes include gains in science self-efficacy, increased use of scientific vocabulary, and an increase in interest in pursuing science educational opportunities and careers in the future.

Finally, outcomes indicate that GE2 can potentially close known male/female and urban/suburban achievement gaps in these areas. Pilot results indicated a differential impact of GE2 between urban and suburban students with respect to written argument quality. Effect sizes ranged from d = 0.30 for suburban females to d = 0.69 for urban males. And where implementation fidelity was extremely high, results indicated even higher gains for suburban females and urban males (d = 2.44 and 1.71, respectively). A similar patterns of positive, differential impact across demographic groups was also noted on the science-related instruments with females, both urban and suburban benefiting the most (d = 0.93) (Lawless et al., 2017).

4 Discussion and Conclusion

PBL-based simulations, like GE2, when designed according to the PBL framework described earlier, are directly linked to curricular standards, and are also intentionally linked to observable and measurable student learning outcomes, can serve as a catalyst for significant changes in how our students perceive and act in the world around them. But, more importantly, simulations of like GE2 can provide students with both a challenging and safe environment within which to gain insight into how they can participate in an impactful manner—in local and global arenas, both now and in the future. Additionally, simulations, like GE2, provide students with opportunities to experience the world from different social perspectives, expanding their understanding and appreciation of the complexities and symbiotic relationships of groups of people that may be currently defined by national borders, beliefs, customs, and/or aspirations (Gehlbach et al., 2008). At the same time, this simulated global environment—reflecting the environments within which these students will be applying these skills—is radically different from traditional and disciplinarily models of instruction that have inhibited exploration of near and far transfer skills, elusive for both students and teachers for too long.

Simulations can bring the world into classrooms at middle grades through college, and to work environments providing rich and dynamic guided experiences for participants as they address the interdisciplinary real-world problems such as *water resources*, *food security,* and *climate change*, critical issues facing all citizens in every country today, and most certainly in the very near future, with even greater immediacy. Moreover, as we have found in our research over the last 10+ years conducting simulations with thousands of students from a broad background of skills and experiences, leveraging the interdisciplinary nature of the field of the social sciences, as GE2 does, provides a context-rich environment for developing significant learning outcomes in other domains, such as science literacy and persuasive writing skills (Brown & Lawless, 2014; Brown et al., 2013; Lawless & Brown, 2015; Lawless et al., 2016). The research findings examining the impact and efficacy of GE2 provide a powerful platform for continued development in how teachers can engage their students in active learning, embedded in meaningful learning environments, that translates to significant and important student growth within and beyond the classroom (Lawless & Brown, in press; Lawless, Brown, & Boyer, 2015; Lawless et al., 2017).

It must be noted that simulations like GE2 require educators to develop and implement a new pedagogical understanding. The role and function of teachers within these simulations requires teachers to transcend the stand-and-deliver model of information transmission. Instead, teachers must model, facilitate, and scaffold the learning of students in an environment that is both dynamic and interactive, and very often ill-defined, providing feedback to their students quickly and realistically. Educators must make their own thinking visible to the students, as they explore new ways of "knowing," gathering data, and representing ideas. Both teachers and their students are challenged, as they engage in the process of finding resources, interpreting "real" data, exploring strategies, interpreting feedback, proposing solutions, and learning to negotiate from different perspectives, in communities of learners. This is especially challenging for both teacher and student when there is often no single "right" answer, but an array of answers informed by different perspectives and different situations, that may vary depending on a number and kinds of contextual factors present. Because of the interdisciplinary nature of these simulations, teachers learn to expand and stretch their own pedagogical knowledge base, disciplinary ways of knowing and communicating that knowledge, and continue to develop their soft skills of teamwork, and communications, modeling their own progress for their students.

The challenges and opportunities of implementing educational simulations must be coupled with support and scaffolding for both students and teachers, through practice, clear expectations, acceptance of changes in the learning processes, support materials tied to the simulation phases, and increased quality professional development (see Lawless & Pellegrino, 2007) that may be delivered throughout the simulation process.

It is our belief that part of what makes GE2 successful are structures of the PBL curriculum, including the development of the problem scenario that is the foundation of the simulation, the three phases of GE2 and the support materials for teachers and students that help them develop structure and context within the ill-defined PBL space of socio-scientific problems, such as global water resources, climate change, and food security. It is these structures and materials that have helped improve implementation fidelity of GE2, ensuring the consistency of student experiences and learning outcomes for thousands of students—preparing them to more fully be prepared to participate as global citizens with an enriched understanding of scientific literacy, now and in the future.

> Be the change that you want to see in the world.
>
> Mahatma Gandhi

References

Anderson, R. D. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education, 13,* 1–12.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Englewood Cliffs, NJ: Prentice-Hall.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. Englewood Cliffs, NJ: Prentice-Hall.

Barton, K. C., & Levstik, L. S. (2004). *Teaching history for the common good*. Mahwah, NJ: Lawrence Erlbaum Associates.

Bednar, A. K., Cunningham, D., Duffy, T. M., & Perry, J. D. (1992). Theory into practice: How do we link? In T. M. Duffy & D. J. Jonassen (Eds.), *Constructivism and the technology of instruction: A conversation*. Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers.

Boyer, M. A., Brown, S. W., Butler, M., Florea, N., Hernandez, M., Johnson, P. R. … Lima, C. O. (2004). Educating for global awareness: Implications for governance and generational change. *Global Change, Peace & Security, 16*(1), 73–77.

Boyer, M. A., Brown, S. W., Butler, M. J., Niv-Solomon, A., Urlacher, B., Hudson, N. F. ... Lima, C. O. (2007). Experimenting with global governance: Understanding the potential for generational change. *Globalisation, Societies and Education, 5*(2), 153–180.

Boyer, M. A., Florea, N., Butler, M., Brown, S. W., Meng, L., Johnson, P. R., & Lima, C., (2005). Understanding security through the eyes of the young, in *The IPE yearbook* published by Lynne Reinner Press.

Brown, S. W. (2007, January). *The GlobalEd project goes international: The Cyprus Project*. Presentation at The Doves Olympic Movement Leadership Conference, Agros, Cyprus.

Brown, S. W., Boyer, M. A., Johnson, P. R., Lima, C. O., Butler, M., Florea, N., & Rich, J. (2004). The GlobalEd Project: Problem-solving and decision making in a web-based PBL. In *Conference Proceedings of Edu-Media, June 24, 2004*. Lugano, Switzerland.

Brown, S. W., Boyer, M. A., Mayall, H. J., Johnson, P. R., Meng, L., Butler, M. J., ... Reis, S. (2003). The GlobalEd project: Gender differences in a problem-based learning environment of international negotiations. *Instructional Science, 31*(4–5), 255–276.

Brown, S. W., & Lawless, K. A. (2014). Promoting students' writing skills in science through an educational simulation: The GlobalEd 2 project. In P. Zaphiris (Ed.) *Human-computer interaction, Part I, HCII 2014, LNCS 8523* (pp. 371–379). Switzerland: Springer International Publishing.

Brown, S. W., Lawless, K. A., & Boyer, M. A., (2009, October). The GlobalEd 2 Project: Expanding the science and literacy curricular space. In T. Bastiaens et al. (Eds.), *Proceedings of World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education 2009* (pp. 160–164). Chesapeake, VA: AACE. Retrieved from http://www.editlib.org/p/32449.

Brown, S. W., Lawless, K. A., & Boyer, M. A. (2013). Promoting positive academic dispositions using a web-based PBL environment: The GlobalEd 2 Project. *Interdisciplinary Journal of Problem-based Learning, 7*(1), 67–90. http://dx.doi.org/10.7771/1541-5015.1389.

Brown, S. W., Lawless, K. A., & Boyer, M. A. (2015). The GlobalEd 2 simulations: Promoting positive academic dispositions in middle school students in a web-based PBL environment (pp. 147–159). In A. Walker, H. Leary, C. Hmelo-Silver, & P. Ertmer (Eds.), *Essential readings in problem-based learning*. West Lafayette, IN: Purdue University Press.

Brown, S. W., Lawless, K. A., Rhoads, C., Newton, S. D., & Lynn, L. (2016, October). Increasing students' science writing skills through a PBL simulation. In D. Sampson, J. M. Spector, D. Ifenthaler, & P. Isaias (Eds.), *Proceedings of The 13th IADIS International Conference Cognition and*

Exploratory Learning in Digital Age (CELDA) (pp. 86–94). Mannheim, Germany: International Association for Development of the Information Society.

Brown, S. W., Lawless, K. A., Newton, S. D., Lynn, L., Riel, J., Song, S., & Oren, J. (2018, February 9). Increasing students' engagement with STEM through a PBL simulation. In *Paper presented at the Annual Meeting of the Eastern Educational Research Association, Clearwater, FL.*

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education, 86*(2), 175–218.

Dede, C. (2009). *Comparing frameworks for 21st century skills*. Harvard Graduate School of Education. Retrieved December 7, 2018, from http://sttechnology.pbworks.com/f/Dede_(2010)_Comparing%20Frameworks%20for%2021st%20Century%20Skills.pdf.

Fadel, C. (2008). *21st century skills: How can you prepare students for the new global economy?* Paper presented at the OECD/CERI Conference in Paris, France in May 2008.

Florea, N., Boyer, M. A., Brown, S. W., Butler, M. J., Hernandez, M., Weir, K. ... Lima, C. (2003). Negotiating from Mars to Venus: Some findings on gender's impact in simulated international negotiations. *Simulation and Games, 34*(2), 226–248.

Gehlbach, H., Brown, S.W., Ioannou, A., Boyer, M.A., Hudson, N., Niv-Solomon, A., … Janik, L. (2008). Increasing interest in social studies: Social perspective-taking and self-efficacy in stimulating simulations. *Contemporary Educational Psychology, 33*, 894–914.

Goodnough, K. C., & Hung, W. (2008). Engaging teachers' pedagogical content knowledge: Adopting a nine-step problem-based learning model. *Interdisciplinary Journal of Problem-based Learning, 2*(2), 61–90.

Graham, S. (2015, April 26). Preparing for the 21st century: Soft skills matter. *Huffington Post*. Retrieved December 8, 2018, from https://www.huffingtonpost.com/stedman-graham/preparing-for-the-21st-ce_b_6738538.html.

Greening, T. (1998). Scaffolding for success in problem-based learning. *Medical Education Online, 3*(4), 1–15.

Hand, B., Yore, L. D., Jagger, S., & Prain, V. (2010). Connecting research in science literacy and classroom practice: A review of science teaching journals in Australia, the UK and the United States, 1998–2008. *Studies in Science Education, 46*(1), 45–68.

Hurd, P. (1998). Science literacy: New minds for a changing world. *Science Education, 82,* 407–418.

Jonassen, D. H. (2009). Assembling and analyzing the building blocks of problem-based learning environments. In K. H. Silber & W. R. Foshay (Eds.), *Handbook of improving performance in the workplace, volume one: Instructional design and training delivery*. Hoboken, NJ: John Wiley & Sons Inc.

Koschmann, T. D., Kelson, A. C., Feltovich, P. J., & Barrows, H. S. (1996). Computer-supported problem-based learning: A principled approach to the use of computers in collaborative learning. In T. Koschmann (Ed.), *CSCL: Theory and practice of an emerging paradigm* (pp. 83–124). Mahwah, NJ: Lawrence Erlbaum.

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

Lawless, K. A., & Brown, S. W. (2015). Developing scientific literacy skills through interdisciplinary, technology-based Global simulations: GlobalEd 2. *The Curriculum Journal, 1,* 1–22. https://doi.org/10.1080/09585176.2015.1009133.

Lawless, K. A., & Brown, S. W. (in press). Promoting global citizenship and STEM literacies with a GlobalEd simulation. In C. Wright-Maley (Ed.), *Teaching life itself: Simulations as powerful and purposeful social studies*. Information Age Publishing; Palgrave.

Lawless, K. A., Brown, S. W., & Boyer, M. A. (2016). Educating students for STEM literacy: GlobalEd 2. In R. D. Lansiquot (Ed.), *Technology, theory and practice in interdisciplinary STEM programs: Connecting STEM and non-STEM approaches* (pp. 53–82). New York, NY: Palgrave Macmillan. ISBN 978-1-137-56738-3. https://doi.org/10.1057/978-1-137-56739-0.

Lawless, K. A., Brown, S. W., Rhoads, C., Lynn, L., Newton, S. D., Brodowiska, K. B., … Song, S. (2017). Promoting students' science literacy skills through a simulation of international negotiations: The GlobalEd 2 project. *Computers in Human Behavior*. https://doi.org/10.1016/j.chb.2017.08.027.

Lawless, K. A., & Pellegrino, J. (2007). Professional development in integrating technology into teaching and learning: Knowns, unknowns, and ways to pursue better questions and answers. *Review of Educational Research, 77*(4), 75–614. https://doi.org/10.3102/0034654307309921.

Mansilla, V. B., Jackson, A., & Jacobs, I. H. (2013). Educating for global competence: Learning redefined for an interconnected world. In *Mastering global literacy* (pp. 5–27). New York: Solution Tree.

McNeill, K. L., & Krajcik, J. (2008). Scientific explanations: Characterizing and evaluating the effects of teachers' instructional practices on student learning. *Journal of Research in Science Teaching, 45*(1), 53–78.

Midgette, E., Haria, P., & MacArthur, C. (2008). The effects of content and audience awareness goals for revision on the persuasive essays of fifth- and eighth-grade students. *Reading and Writing, 21*(1–2), 131–151.

Millar, R., & Osborne, J. (Eds.). (1998). *Beyond 2000: Science education for the future*. London: King's College, School of Education. Retrieved from http://www.nuffieldfoundation.org/sites/default/files/Beyond%202000.pdf.

Monk, M., & Osborne, J. (1997). Placing the history and philosophy of science on the curriculum: A model for the development of pedagogy. *Science Education, 81,* 405–424.

National Research Council (NRC). (1996). *National science education standards*. Washington, DC: National Academy Press.

National Research Council (NRC). (2011). Retrieved June 15, 2012, from http://www.nap.edu/catalog.php?record_idD13165.

Newcombe, N. S., Ambady, N., Eccles, J., Gomez, L., Klahr, D., Linn, M., Miller, K., & Mix, K. (2009). Psychology's role in mathematics and science education. *American Psychologist, 64*(6), 538–550.

Next Generation Science Standards (NGSS). (2013). Retrieved January 12, 2018, from https://www.nextgenscience.org/.

Osborne, J. F., Erduran, S., & Simon, S. (2004). *Ideas, evidence and argument in science: In-service training pack, resource pack and video*. London: Nuffield Foundation.

Pajares, F. (1996). Self-efficacy beliefs in academic settings. *Review of Educational Research, 56*, 543–578.

Picho, K., & Brown, S. W. (2011). Can stereotype threat be measured? A validation of the social identities and attitudes scale (SIAS). *Journal of Advanced Academics, 22*(3), 374–411.

Riel, J., Lawless, K. A., & Brown, S. W. (2016). Listening to the teachers: Using weekly online teacher logs for ROPD to identify teachers' persistent challenges when implementing a blended learning curriculum. *Journal of Online Learning Research, 2*(2), 169–200.

Riel, J., Lawless, K. A., & Brown, S. W. (2017). Defining and designing responsive online professional development (ROPD): A framework to support curriculum implementation. In T. Kidd & L.R. Morris, Jr. (Eds.), *Handbook of research on instructional systems and technology* (Chapter 10, pp. 104–115). Hershey, PA: IGI Global. ISBN 9781522523994.

Riel, J., Lawless, K., & Brown, S. W. (2018). Timing matters: Approaches for measuring and visualizing behaviours of timing and spacing of work in self-paced online teacher professional development courses. *Journal of Learning Analytics, 5*(1), 25–40. https://doi.org/10.18608/jla.2018.51.3.

Rose, S. L., & Barton, A. C. (2012). Should Great Lakes city build a new power plant? How youth navigate socioscientific issues. *Journal of Research in Science Teaching, 49*(5), 541–567.

Sadler, T. D. (2009). Situated learning in science education: Socio-scientific issues as contexts for practice. *Studies in Science Education, 45,* 1–42.

Sadler, T. D., Romine, W. L., & Topçu, M. S. (2016). Learning science content through socio-scientific issues-based instruction: a multi-level assessment study. *International Journal of Science Education, 38*(10), 1622–1635.

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 educational technology* (2nd printing ed.). Englewood Cliffs, N.J.: Educational Technology Publications.

Scheiner, S., & Willig, M. R. (2008). A general theory of ecology. *Theoretical Ecology, 1*(1), 21–28.

Schrader, P. G., & Lawless, K. A. (2004). The knowledge, attitudes, and behaviors approach: How to evaluate performance and learning in complex environments. *Journal of Performance Improvement Quarterly, 43*(9), 8–15.

Schwarz, B. B., Neuman, Y., Gil, J., & Ilya, M. (2003). Construction of collective and individual knowledge in argumentative activity: An empirical study. *The Journal of the Learning Sciences, 12*(2), 221–258.

Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education, 88*, 610–645.

Steele, C. M. (1997). A threat in the air: How stereotypes shape intellectual identity and performance. *American Psychologist, 52,* 613–629.

Toulmin, S. (1958). *The uses of argument*. Cambridge, MA: Cambridge University Press.

Wenger, E. (1998). Communities of practice: Learning as a social system. Published in *The Systems Thinker*. Retrieved from https://thesystemsthinker.com/communities-of-practice-learning-as-a-social-system/.

Yukhymenko, M. (2011). Students' interest in social studies and negotiation self-efficacy: A meta-analysis of the GlobalEd project. *Journal of Technology and Teacher Education, 19*(3), 369–392.

Zhao, Y. (2009). *Catching up or leading the way: American education in the age of globalization*. Alexandria, VA: ASCD.

Zimmerman, B. J. (1989). A social cognitive view of self-regulated academic learning. *Journal of Educational Psychology, 81,* 329–339.

Chapter 16
Design a Collaborative Visualization-Based Learning System for Problem-Solving to Transform the Classroom Ecosystem

Huiying Cai and Xiaoqing Gu

1 Introduction

From the psychology perspective, individuals' developments are the results of interactions within different ecology systems around them (Urie, 1979). According to Urie (1979), those ecology systems varied from the macro-level ones, such as the environment with certain social-cultural or with the certain rules and regulation to the micro-level ones, such as family or school. To some extent, the classroom can be viewed as an ecology system. In the classroom ecology system, students spent most of their time interacting with teacher or other classmates. The quality of interaction happening in the classroom ecosystems is very important for individual's development (Morgan & Martin, 2014). As for the classroom ecology system, there are two subsystems, that is, the interactive sub-ecosystem between teacher and students and the interactive sub-ecosystem between students (Chen & Li, 2008). However, in practice, the quality of interaction within the two sub-ecosystems did not seem progress well. On the one hand, in the traditional classroom setting, teachers were likely to pass knowledge to students by lecture. In this situation, students achieved knowledge inactively. Therefore, the poor quality of interaction between teacher and students did not contribute to individual's development effectively. On the other hand, many researches in computer-supported collaborative learning (CSCL) demonstrated that the effective social interaction during problem-solving between learners did not happen spontaneously when students were assigned into the same group (Weinberger,

H. Cai
Department of Educational Technology, Jiangnan University, Wuxi, Jiangsu, China
e-mail: caihy@jiangnan.edu.cn

Research Center of Educational Informatization, Jiangnan University, Wuxi, Jiangsu, China

X. Gu (✉)
Department of Education Information Technology, Faculty of Education, East China Normal University, Shanghai, China
e-mail: xqgu@ses.ecnu.edu.cn

P. Díaz et al. (eds.), *Learning in a Digital World*, Smart Computing and Intelligence, https://doi.org/10.1007/978-981-13-8265-9_16

Ertl, Fischer, & Mandl, 2005). What's more, if students in some group lacked extra support to complete the complex tasks collaboratively, they could not benefit from the social interaction during problem-solving (Vogel, Wecker, Kollar, & Fischer, 2017). Therefore, how to facilitate effective social interaction in the two sub-ecosystems of classroom setting is the key issue to address in education research.

In education technology, there is the common sense that information and communication technologies (ICT) have the potential to transform the ecology of teaching and learning in the twenty-first century (Somekh, 2007). Among the various ICT, many researches in the CSCL community demonstrated that external representation is a suitable technological support for social interaction based on cognitive load theory (see van Bruggen, Kirschner, & Jochems, 2002). In comparison with a text-based external representations tool, the diagram-based external representation tool plays an important role in the cognitive and social aspects of learning (Suthers, 2001). It can help learners externalize information processing, see patterns, express abstract ideas with concrete forms, and discover new relationships while solving problems. In addition, visualization tools can help learners use artifacts to share questions and ideas in groups, and record the groups' argumentation processes. Therefore, the diagram-based external representation tool could enhance levels of deep understanding by making the shared graphical representations act as scaffold for social interaction (Gijlers & de Jong, 2013; Scheuer, Loll, Pinkwart & McLaren, 2010). Based on it, we intend to design the collaborative visualization-based learning system to transform the traditional classroom ecosystem. We expect that the collaborative visualization-based learning system not only effectively influence the interaction between teacher and student in the classroom level but also impact the interaction between students in the group level.

In the following part, we first review the existing researches related to diagram-based external representation tool. Then the prototype of designing the collaborative visualization-based learning system named semantic diagram tool is proposed. To investigate its effectiveness, two cases integrated with semantic diagram tool were designed, implemented, and analyzed. Based on the two cases, we discuss the value, benefit, and limitations of integration of the collaborative visualization-based learning system into classroom. At last, we propose the future researches, such as designing the collaborative visualization-based learning system and designing the teacher's training program based on the learning system.

2 Semantic Diagram Tools: The Collaborative Visualization-Based Learning System for Problem-Solving

There are different types of the diagram-based external representation tools for supporting social interaction during problem-solving, such as mapping concepts, organizing graphics, and threading ideas. A concept mapping tool provides visual cues, such as texts, shapes, and line-labeled arrows, to present individuals' understanding of relationships between concepts, or to present individuals' knowledge structures (Novak & Canas 2008). Research found that digital concept maps can display shared knowledge and allow involved learners to focus on information relevant to the problem at hand, which can support interaction in group learning (Wang, Cheng, Chen, Mercer, & Kirschner, 2017). Graphic organizers are visual and spatial displays designed to facilitate the teaching and learning through the "use of lines, arrows, and a spatial arrangement that describe text content, structure, and key conceptual relationships." It includes semantic maps, cognitive maps, story maps, framed outlines, and Venn diagrams (Kim, Vaughn, Wanzek, & Wei, 2004). van Amelsvoort et al. (2007) reported that graphic diagram functioned as important inputs for the discussion phase and can improve the breadth and depth of group discussions. The visualization tools such as Idea Thread Mapper can externalize and trace the processes of problem-solving. Using the Idea Thread Mapper, students were reminded to reflect on their own thinking, to be aware of and incorporate their community's knowledge, and to make further efforts to collaborate with their peers (Chen et al. 2013).

Considering the characteristics of diagram-based external representation tools to support CPS, the collaborative visualization-based learning environment, named the semantic diagram, was designed to structure problem-solving in the classroom setting. The semantic diagram can utilize graphics, images, and other visual elements to visualize the group's knowledge and understanding of concepts, principles, and concept relations (Gu & Quan 2014). Based on the existing researches, we identified two aspects of technology support of semantic diagram tool, namely, the functions to provide both conceptual support and socio-cognitive support for student's collaborative problem-solving (Cai, Lin, & Gu, 2016; Ertl, Fischer, & Mandl, 2006). For conceptual support, semantic diagram tool can help learners diagrammatically represent the logical structure of knowledge within the learning task. It has the potential to externalize students' understanding of the logic and semantic interrelationships among different concepts. For socio-cognitive support, the semantic diagram tool can help learners diagrammatically represent the collaboration process. It has the potential to stimulate the group's in-depth discussions based on the co-constructed learning artifacts, and also to trace the process of problem-solving for improving students' reflection and awareness during their collaboration. Therefore, semantic diagram tool can record, externalize, and trace both the individual and group learning processes, and can stimulate learners to think and reflect during the CPS process. Following the characteristics of collaborative visualization-based tools mentioned above, the semantic diagram has the potential to: (1) externalize group students' understanding of the logic and semantic interrelationships among different concepts, (2) stimulate the group students' in-depth discussions based on the co-constructed learning artifacts during social learning activities, and (3) trace the process of problem-solving to improve students' reflection and awareness during collaboration.

There are two typical semantic diagram tools, named Metafora platform and Mural, which will be integrated into the two following empirical research cases, respectively. Metafora platform is the learning system designed in the Metafora project to support group students' collective reflection and improvement of social learning in forums (Dragon et al. 2013; Harrer et al. 2013). In the Metafora platform, the Planning Tool can be used to make the plan of problem-solving visualized, which can provide concept support for problem-solving. The Planning Tool provides a set of icons called Visual Language Cards to present different steps for solving problems. These include 12 activity stage cards and 18 activity process cards. The stage cards include high-level activities such as exploring a phenomenon while the process cards provide methods and stages including discussing alternatives. The cards contain titles and visual symbols representing various learning activities, so that the map created by a group within the Planning Tool can be considered as a visual language for the students to describe what they intended to do in different phases of the problem-solving process. What's more, there is another tool in the Metafora platform named LASAD, which stands for Learning to Argue: Generalized Support Across Domains. It is a dynamic discussion-mapping tool for constructing and deconstructing collaborative arguments, which can provide socio-cognitive support for problem-solving. LASAD helps to define the knowledge elements of an argument. LASAD can provide a learning space for the students to implement argument rules and to express, discuss, and reflect ideas in a joint learning environment. Mural is an online collaborative concept mapping tool. Using the concept support of Mural, it can aid learners to visualize their logical and structural understanding of different concepts. Students could add text, titles, pictures, icons, documents, URLs, and connecting arrows to represent their understanding of concepts and the relationships between them. Using the socio-cognitive support of Mural, students can simultaneously and freely manage different elements to co-construct knowledge models in the joint Mural interface.

In this study, semantic diagram tool is proposed as the driver to transform the classroom ecosystem when conducting problem-solving project. In order to investigate whether and how semantic diagram tool influences the classroom ecosystem, two studies were designed, implemented, and analyzed in Shanghai, China. Two research questions are tried to answer. (Q1) How does semantic diagram tool influence the interactive sub-ecosystem between teacher and students during problem-solving? (Q2) How does semantic diagram tool influence the interactive sub-ecosystem between students in a group during problem-solving? The potential significance of the work is to provide practical insights of how to integrate learning technology into classroom for teachers, as well as reflective insights of refining the technological tool for problem-solving in the classroom setting.

3 The Research Design

In order to explore how semantic diagram tool influence the interactive sub-ecosystem between teacher and students, case 1 was designed and implemented at a primary school in Shanghai, China, in which the semantic diagram tool named Metafora was integrated into a single problem-solving project. In this case, we collected the discourse between teacher and students in the class level by video for analysis. In order to explore how semantic diagram tool influenced the interactive sub-ecosystem between students in the group, case 2 was conducted in a university in Shanghai, China. In this case, we designed the comparative experiments. The semantic diagram tool was integrated in the problem-solving project in one condition, which is called diagram-based tool condition (DT). While the text-based tool as the alternative was integrated in the same collaborative problem-solving project in another condition, which is called text-based tool condition (TT). In this case, we collected the discourse between students in the group level in the two conditions for analysis, which were recorded by the synchronous chat tool named QQ.

3.1 The Research Design of Case 1

3.1.1 Participant and Research Context

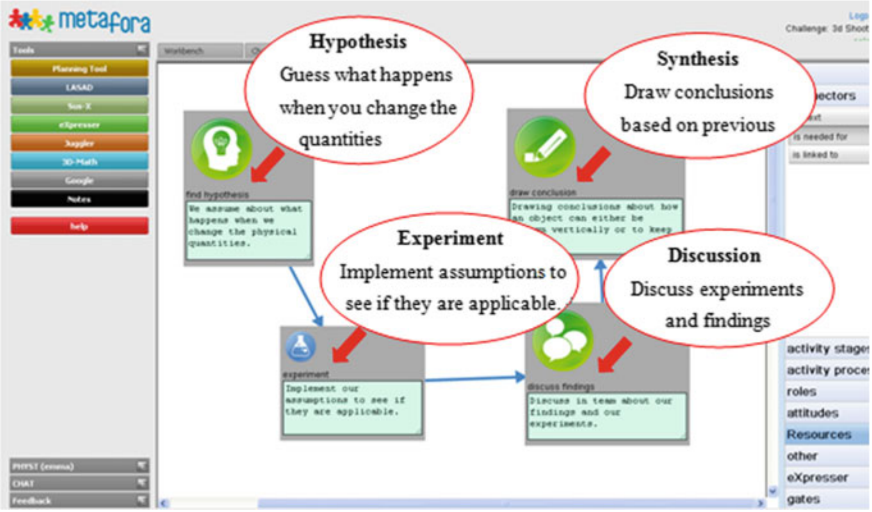
Twenty-one fifth-grade students (8 males, 13 females, mean age = 9.95 years, SD = 0.59) from a primary school in Shanghai, China took part in the problem-solving project. The science teacher with more than 10 years of teaching experience from the same school also participated in the CPS project. In order to make the semantic diagram tool integrated into the problem-solving project well, the research team which included a lead researcher and three research assistants co-designed the CPS project with the science teacher. After completing the instructional design of the problem-solving project, she implemented the problem-solving project in her class.

3.1.2 The Design of Problem-Solving Project Integrated Metafora

The problem-solving project was co-designed between the science teacher and the research team in four rounds of face-to-face communication (30 min each time). Based on the learning topic Food and Nutrition in the fifth-grade science curriculum, four sequential learning sessions of the problem-solving project (60 min per session) were designed. The aim of each learning session was: (1) to classify the given food according to nutritional values, (2) to detect the main nutritional composition of a given food, (3) to discuss the function of a certain nutritional value, and (4) to evaluate a family's diet for 1 week and develop a healthy diet plan for the family. After several cycles of revision took place between the teacher and the research team, the Metafora was properly integrated into each session of the problem-solving project to optimize its benefit in structuring problem-solving learning process (see Cai, Lin, & Gu, 2016). The interface of the two tools is seen in Figs. 1 and 2.

3.1.3 Experiment Procedure and Data Collection

The designed problem-solving project took place in science classroom. The classroom was equipped with the Internet connection, an electronic projector, teacher



Hypothesis
Guess what happens when you change the quantities

Synthesis
Draw conclusions based on previous

Experiment
Implement assumptions to see if they are applicable.

Discussion
Discuss experiments and findings

We assume about what happens when we change the physical quantities.

Implement our assumptions to see if they are applicable.

Discuss in team about our findings and our experiments.

Drawing conclusions about how an object can either be ...ns vertically or to keep

Fig. 1 Screenshot of the planning tool in the Metafora platform

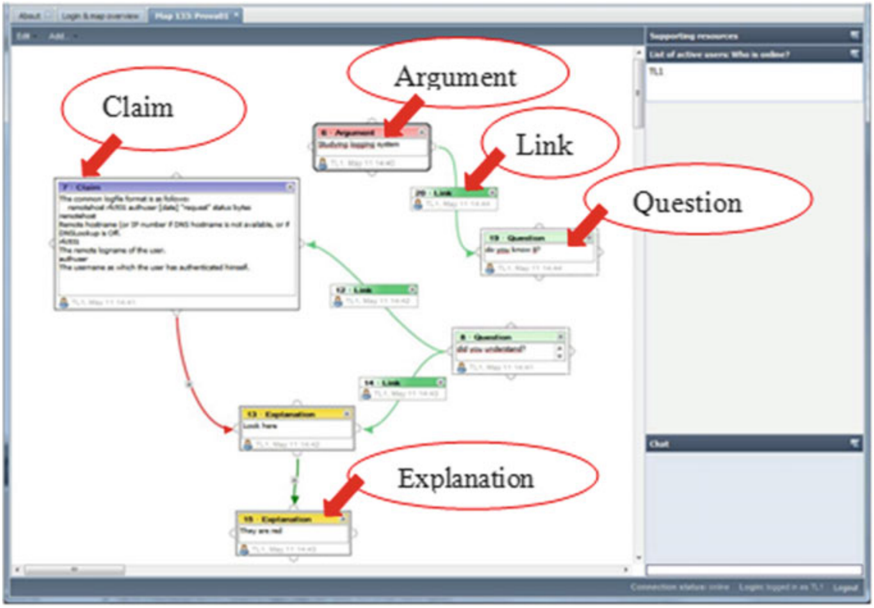


Fig. 2 Screenshot of LASAD in the Metafora platform

computer, and whiteboard. Since there were five computers equipped with Metafora, the 21 participants were randomly divided into five groups. There were four groups with four students, and one group with five students.

Teacher implemented the problem-solving project in the four sequential learning sessions (60 min per session). Each group students finish the problem-solving project under the guidance of the science teacher. During implementation, the research team's primary role was to troubleshoot technical problems such as installing Metafora in the classroom and helping students to log into the learning platform. They recorded the whole learning session and made the classroom observation, which would act as data resource for analyzing.

3.2 The Research Design of Case 2

3.2.1 Participant and Research Context

Forty-nine first-year graduate students finally participated in the study following an open invitation (involving some last minute withdrawals and additions). They majored in education at the same university in Shanghai, China. They were assigned to one of two conditions: a diagramming condition (DT, n = 23) with the tool "Mural" (https://mural.co/), or they were assigned to a text construction tool condition (TT, n = 26) with "Shimo" (https://shimo.im/). Consider that three or four members is a preferred group size during collaborative learning. The assignment method resulted in eight peer groups in two conditions. In TT, there were six triadic groups and two four-person groups. In DT, there were seven triadic groups and a single pair group (one participant withdrew after the experiment began, so the total number of participants in DT is 23).

3.2.2 The Design of Problem-Solving Project

In the problem-solving project, the overarching topic for collaboration was "Making instructional design for future classrooms". This established the problem-solving task at a complex level of open-ended problem-solving. Group learners would build understanding of this topic through active problem-solving ("high-level" engagement), rather than through simply memorizing domain-specific knowledge ("low-level" engagement). Two interdependent activities were predesigned to support learning by structuring the open-ended problem. These were goal related but combined to provide group learners with hints or cues.

The first learning session is about the Learning Theory task. In this session, three interdependent subtasks were designed based on learning theory and classroom teaching. The subtask 1 is to record and share understanding of three learning theories. Three short descriptions of learning theories with the same descriptive structure were distributed to different students in the groups. Individual students in a group were expected to simultaneously draw and combine their own understandings of specific learning theories in the shared space. The subtask 2 is to contrast traditional and future classrooms from learning theory perspectives. Two five-minute videos of classroom teaching served for discussion material. One showed a traditional classroom scenario and one was set in a "future classroom". The subtask 3 is to discuss and determine the characteristics of future classroom teaching based on the above two subtasks.

The second learning session is about the Bloom/Instruction task. In this session, three, two interdependent subtasks were designed on the basics of Bloom's taxonomy and instruction design. The subtask 1 is to record and share understanding of Bloom's taxonomy after reading complementary learning materials. Basic learning material relating to Bloom's taxonomy was introduced to each student. Then three types of applied learning material concerning this taxonomy were distributed to each student in a group. Individual students were expected to synthesize the application of Bloom's taxonomy in the shared learning space. The subtask 2 is to evaluate two instructional design cases from the perspective of Bloom's taxonomy. Two cases with the same learning topic were assigned to each student. The groups were required to compare the differences and then evaluate them through Bloom's taxonomy.

3.2.3 Experiment Procedure and Data Collection

Groups in DT used Mural to complete the problem-solving project while groups in TT used Shimo to complete the same project. In one condition ("DT" or diagram tool condition), the established tool Mural was used as a semantic diagram tool. The character of this tool is summarized in Fig. 3. In the TT condition, the well-established online collaborative document tool, Shimo, was used. Similar to Mural, Shimo can provide conceptual and social support for CPS. The difference is that Shimo can only linearly externalize the task space. Shimo supports group members in simultaneously co-editing and expanding linear documents in the same interface. Students could add text, tables, and URLs. The character of this tool is summarized in Fig. 4.

The two experiments took place on different days but at the same computer lab. Members of each group shared the same room but were located at individual workstations from which they communicated with their peers. During the study, students working in a shared space in Mural or Shimo were asked to communicate with their team only through the synchronous chat tool QQ. The tool enabled group members to create synchronous discussion privately and simultaneously, which resulted in a transcript of the group discussion as a text file. According to DT/TT allocations, either Mural or Shimo was continuously visible in each group participant's screen interface for reading and editing.

After the 35 min individual pre-test, all students took 20 min to familiarize themselves with the learning tools, creating user accounts on their own representational tool (Mural or Shimo), and practicing the main functions with the help of research assistants. The background information of the problem-solving project was then explained to them in five minutes. Next, the students in both conditions were trained

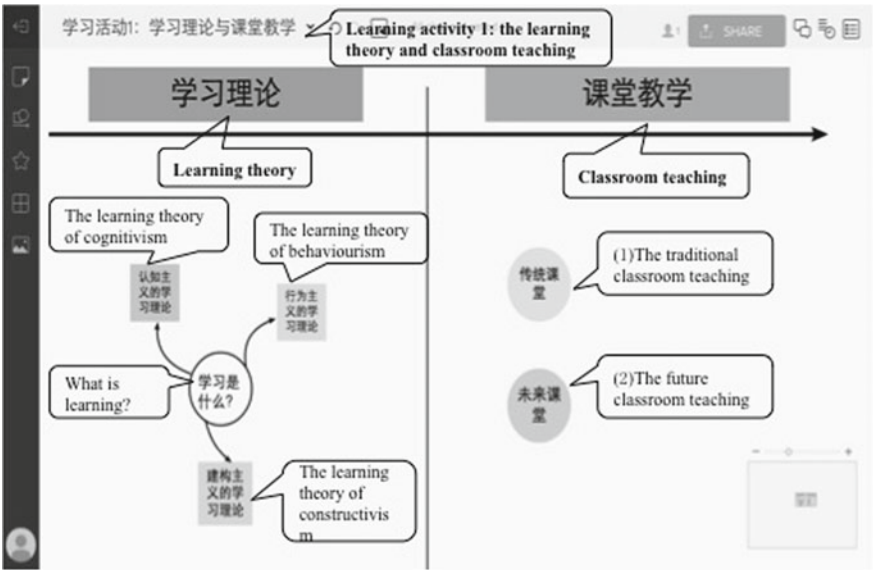
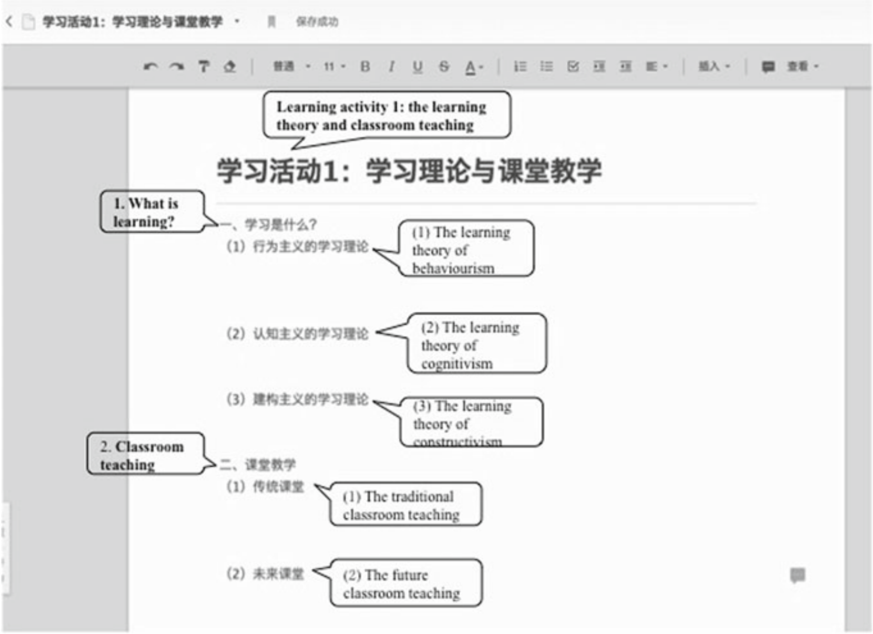


Fig. 3 Interface and functional outline of Mural



学习活动1：学习理论与课堂教学

一、学习是什么？
（1）行为主义的学习理论
（2）认知主义的学习理论
（3）建构主义的学习理论

二、课堂教学
（1）传统课堂
（2）未来课堂

Fig. 4 Interface and functional outline of Shimo in basic group discourse strategies (Wegerif & Mansour, 2010). In order to address relative unfamiliarity with diagram mapping, those in the DT condition were provided with 40 min of DT training, following the practice recommended by Jin and Wong (2010).

At the start of both the learning theory and Bloom/instruction tasks, students were assigned the scripted instructional materials. Thereafter, students should finish the learning task in the specified "task space" designed for each group. The support tool interface in the first task is shown in Figs. 3 and 4, respectively. Each task lasted approximately 60 min with groups setting their own learning pace and deciding when they had reached a conclusion, communicating throughout with the QQ tool. The whole problem-solving project was overseen by four research assistants. At the end of the problem-solving project, each student took an individual subject knowledge post-test for around 35 min, without access to the learning materials.

4 Data Analysis

To answer the research question 1, we analyzed the classroom discourse data recorded in the classroom videos in case 1. To answer the research question 2, we analyzed and compared the group discourse data recorded in QQ in the two conditions in case 2. When analyzing the classroom discourse data from case 1 and the group discourse data from case 2, the unit of data analysis is the learning event, which refers to an undivided pedagogical episode where a series of uninterrupted interaction moves with the same semantic content between learners and/or teachers (Prieto et al. 2011; Wen et al. 2015). It can be used to capture the interaction between learners and/or teachers, which they engaged into during the learning process of problem-solving.

4.1 The Analysis of Data from Case 1

In case 1, the videos of four classroom sessions were first transcribed based on the words of the teacher and her students (see the first three columns in Table 1). Then the learning events were extracted and labeled with the pedagogical meaning of the learning activities. Afterward, the person (either the teacher or a student) who led the activity was noted accordingly. Table 1 shows some excerpts of the coding of the classroom activities. For example, at the time of "00:13:50–00:14:50", the teacher, student 1, and student 2 had a conversation. Depending on the content of the conversation, the event could be named as "introduce the learning topic", which was led by the "teacher". Because there were four other events before the time of "00:13:50", the event of "introduce the learning topic activity" was named number "5". Based on the coding schema, 39 events were identified in the four classroom video recordings. Two research assistants coded the transcribed data of four classroom sessions independently. Then their coding results were compared

Table 1 Excerpt coding examples and results of classroom activities

Time	Role	Activities	Meaning of the pedagogical block	Led by
00:13:50	T	Today we will learn about food and nutrition. (T writes on the blackboard). What questions would you like to ask when you see these words?	5. Introduction of the learning topic	Teacher
	S1	Which food does it point to?		
	S2	What is the nutritional value?		
00:14:50	T	Ok. What nutritional value does the food contain? Different kinds of food contain different nutritional values. Today, we will research this question		Teacher
00:15:03	T	Next, I will assign a table to every group. The table shows names and nutritional values of the food. Please read the table carefully and share what you find in your group. After every group finishes the discussions, I will ask each group to report your findings	6. Distribution of materials and group tasks	Teacher
00:15:10	G	(Groups start discussions)	7. Group discussions	Student
00:20:02	G	(Groups end discussions)		

Note T = teacher; S1 = student 1; S2 = student 2; G = group

and negotiated, resulting in 39 events being identified in the implication of the whole problem-solving project.

In order to understand the roles of the semantic diagram and the teacher during the learning process of problem-solving, we used the framework of Dillenbourg (2013) to categorize the 39 events. Dillenbourg (2013) claimed that a classroom is a continuum of activities ranging from intrinsic to extrinsic learning. It included five types of learning activities, namely, core activities, emergent activities, envelope activities, extraneous events, and the infra activities from the center to the periphery. According to the function of the event playing in the implication of the whole problem-solving project, we categorize the identified 39 events by the framework of Dillenbourg (2013). Table 2 below shows the category with examples. For example, the activity, “2. Discussing group rules on LASAD,” was a main part in the warm-up activity 1; therefore, it was placed in the category of “Core activity.” The event “6. Logging in the Planning Tool,” did not constitute a meaningful part of the scenario but was necessary to run it, so it was placed into the category of “Infra activities”.

Table 2 The coding schema of the pedagogical activity in the CPS classroom continuum

Activity categories	Descriptions	Examples of pedagogical block
Core activities	Designed as adaptive: The activities of the scenario are predefined with certain adaptations to be performed by the system or by the teacher	2. Discuss group rules using LASAD
Emergent activities	Designed as contingent: Some scenarios include activities with contents unpredictable because they build upon what learners produced in earlier phases of the scenario	3. Group report 10. Class brainstorm
Envelope activity	Routinized: Some classroom activities are not part of the pedagogical design but are established school practices	5. Introduce learning topic
Extraneous events	Unavoidable: A designed scenario which prepares for unexpected events	30. Review the function of Planning Tool
Infra activities	Necessary: activities that do not constitute a meaningful part of the scenario but are necessary to run	6. Log in Planning Tool 21. Assign learning materials

The 39 events were further categorized by functions performed to complete the tasks according to Prieto et al. (2011)'s framework. With this framework, the teacher's activities were categorized into "explanation", "support", and "assessment", while the students' activities were categorized into "group discussion" and "group report", and "others". Different shapes were used to present different categories of activities, as shown in Table 3. The event "1. Introduce group rules" was performed by the teacher as a function of explanation, so the coding shape of the event was a circle. The event "2. Discuss group rules" was performed by the students as a function of discussion, so the coding shape of that event was a square.

4.2 The Analysis of Data from Case 2

In case 2, the learning event is exacted from group discourse recorded by QQ. The information for each utterance from QQ were recorded not only who talked and what was said but also when it was said. These recordings could be used to explore what kind of learning activity group engaged into during the problem-solving task (Wegerif et al., 2010). Considering that in a specific event a distinct discourse topic was discussed within a group across a period of time, ending with a confirmation that at least two learners understood each other (Slof, Erkens, Kirschner, & Helms-

Table 3 The coding schema of teacher's and students' activity in the CPS project

Roles	Activity categories	Explanations	Examples	Coding shapes
Teacher's activities	Explain	Provide an overview of activities	1. Introduce group rule. 29. Review how to make a plan using the Planning Tool	○
	Support	Provide support for learning activities	6. Distribute materials and assign group tasks 15. Show experiment tools	△
	Assess	Evaluate results of learning tasks	20. Complete experiments	⬡
Students' activities	Discuss	Discuss learning tasks	2. Discuss group rules 10. Brainstorm	□
	Report	Report learning tasks	3. Group report	⬠
	Other	Other student's activity	13. Observe experiment	⏢

Lorenz, 2013). The identified learning event was first coded with Rainbow Analysis categories (Baker, Andriessen, Lund, van Amelsvoort, & Quignard, 2007), and then with Functional Category System (Poole & Holmes, 1995) (see Table 4). The first was used to identify the type of learning event that a group engaged in, whereas the second was used to identify the discourse function of each subtype of learning events based on the first coding result. The coding schema for group discourse during problem-solving is reviewed in Table 4. According to the coding schema, if groups engaged in the social-related or task-related learning events more often, it implies that group members did not register group progress or task progress so confidently. These kinds of learning experiences may be not helpful to the construction and storage of schemata because there are no to-be-learned materials involved during these learning events. While, if groups experienced the cognitive-related learning events well, it can be inferred that groups will have a greater probability of achieving the construction and storage of schemata, which will be effective for learning.

Specifically, some episode examples of coding group discourses during problem-solving are shown in Table 5. For example, from the time of 14:47:58 to 14:48:23, three learners in a group were discussing how to divide the task. According to the discussion content, it could be identified as a social-related learning event(S). Then,

Table 4 The coding scheme for group dialogues during problem-solving

Learning event	Discourse function	Description	Coding
Outside (O)	Technology-related issue (T)	Any interaction concerned with technology problems	O-T
	Other issue (O)	Any interaction not concerned with interacting to carry out the task, e.g., talk about tonight's plan	O-O
Socially-related (S)	Group Plan (GP)	Discussing collaboration strategies instead of task-related strategies, such as helping each other or proposing to work together on certain tasks	S-GP
	Group Monitor (GM)	Exchanging information to monitor group processes	S-GM
Task-related (T)	Task Orientation (TO)	Exchanging and sharing task-related information; discussion of strategies necessary to complete the task, choice of appropriate strategies, and delegation of task responsibilities	T-TO
	Task Management (TM)	Exchanging of information to monitor task performance and progress, or assess the amount of time available	T-TM
Cognitive-related (C)	Group-Individual learning activity (GI)	Co-constructing knowledge models in a shared task space simultaneously by individuals in a group	C-GI
	Group Artifact-based learning activity (GA)	Reviewing group's artifact and make some change and comment on the artifact by individual in a group	C-GA
	Artifact-based Discussion activity (AD)	Making a discussion based on the learning artifact and make a summary of certain learning task	C-AD

Table 5 Example of the coding episode of group dialogues during problem-solving

Time	Talker	Content	Coding result
14:47:58	A	I response for constructivism	S-GP
14:48:08	B	I response for cognitivism	
14:48:14	C	OK	
14:48:18	C	I response for behaviorism	
14:48:23	B	OK	
			C-GI
15:15:50	A	Do you finish task 1?	S-GC
15:15:56	B	OK	
15:16:07	C	OK	
15:16:38	B	Should we review the contents added by each other?	T-TM
15:16:39	A	We should discuss first and then make some revision	
15:16:50	A	OK	
15:16:54	C	I agree it	
			C-GA
15:20:47	A	Then?	T-TO
15:20:56	C	To ask question	
15:21:02	C	To add some comments	
15:21:29	C	To also check whether there are any revise	
15:22:48	C	Should I add comments on the content made by myself or on the content made by others?	
15:23:06	A	On the content made by others	
15:23:29	C	OK	

according to the discourse function, the learning event was for Group Plan (GP). Therefore, the episode of group discourse was coded as "S-GP" in the end. Two research assistants, who had 1 h of prior training, coded the dialogue data. The different coding results were negotiated until consensus was achieved. After completing the two-level coding of each group's discourse, the duration times of each subtype of learning event were calculated. As shown in Table 5, the learning event S-GP started at 14:47:58 and ended at 14:48:23. So the duration of S-GP was 25 s. These calculations were used to determine the durations of group engagement in the learning event during CPS.

5 Findings

5.1 How Does Semantic Diagram Tool Influence the Interactive Sub-ecosystem Between Teacher and Students During Problem-Solving

The mediated effect of semantic diagram tool on the interaction between teacher and students during problem-solving is deeply explored in case 1. From Fig. 5, we found that for the 39 learning events, (1) the "core activities" were mainly used to support by the Planning Tool or LASAD. (2) The emergent activities only took place when the visualized learning artifacts on LASAD or the Planning Tool were created. (3) The last three types of learning events labeled by gray circles were led by the teacher. During the class observations, we also noticed that the teacher led the classroom progress, assigned learning tasks to the students, and coordinated the students' activities at the class level. Therefore, we conclude that integration of semantic diagram tool can influence the flow of the interaction between teacher and students during the problem-solving classroom. Specifically, the semantic diagram played a critical role in supporting and stimulating intrinsic activities and teacher played an indispensable role in the extrinsic learning activities during the flow of problem-solving project. As we know, the learning activities supported by Planning Tool or LASAD were mainly performed by students in group. It inferred that with the integration of semantic diagram tool, the extrinsic learning activities in problem-solving project are led by students.

What's more, as shown in Fig. 6, there were 23 student-led learning events and 16 teacher-led learning events. The student-led learning events, including the group reports and group discussions, comprised of 6/39 (15.4%) and 12/39 (30.8%) of all the classroom activities, respectively. There were more group-centered learning activities than other kinds of activities. This means that in the problem-solving project, students had many opportunities for communication and collaboration. What's more, it was found that the teacher had a higher percentage of non-lecture activities. For

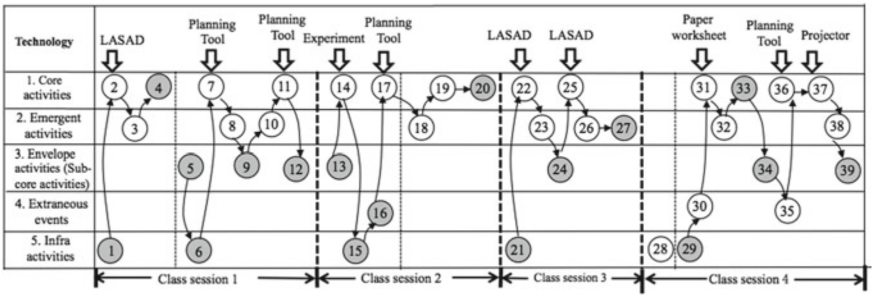


Fig. 5 The pedagogical flow of the problem-solving project in case 1

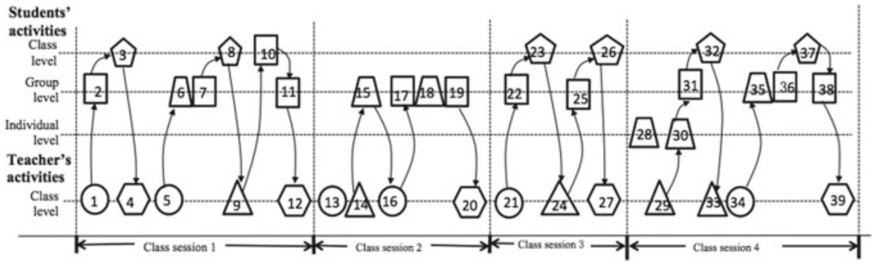


Fig. 6 The flow of teacher and students' activities in the problem-solving project in case 1

instance, the teacher had more question promoting activities (5/16, 43.75%), and evaluative activities (5/16, 37.5%), than lecture-oriented activities (6/16, 18.75% for introducing activities). This indicates that the teacher acted as the learning facilitator rather than knowledge transmitter during the problem-solving project. This finding was consistent with the classroom observations. When students were busy with the learning activities in Metafora, the teacher was freed from the knowledge transmission. The teacher had more time to watch and guide the groups' discussions and reports, and to provide detailed instructions for activities. Therefore, it can be concluded that, compared to the traditional teacher-centered lecture approach, this project showed a trend toward student-centered learning.

5.2 How Does Semantic Diagram Tool Influence the Interactive Sub-ecosystem Between Students in the Group During Problem-Solving

The mediated effect of semantic diagram tool on the interaction between students in the group during problem-solving is explored in case 2. First, we found that the time taken by each group to complete the whole problem-solving learning project was significantly different under the two conditions, $T(14) = 5.62$, $p < 0.001$, $d = 3.00$. The time that groups spent in TT was significantly longer ($M = 9029.8$ s, $SD = 551.02$) than that in DT ($M = 7757.0$ s, $SD = 327.44$). This means that the integration of the semantic diagram tool shortened learners' total learning time in the CPS project.

Second, a chi-square test revealed that the proportion of time students engaged in the four types of learning event (O-T-S-C) was significantly different between the two conditions, $X^2(3) = 148.43$, $p < 0.001$. This difference is elaborated in Fig. 7, where shaded dots identify "cognitive learning events", dark oblique lines are "outside learning events", light oblique lines "social-related learning events", and vertical lines "task-related learning events". There were clearer differences in percentage engagement time in terms of cognitive-related and social-related learning events. As

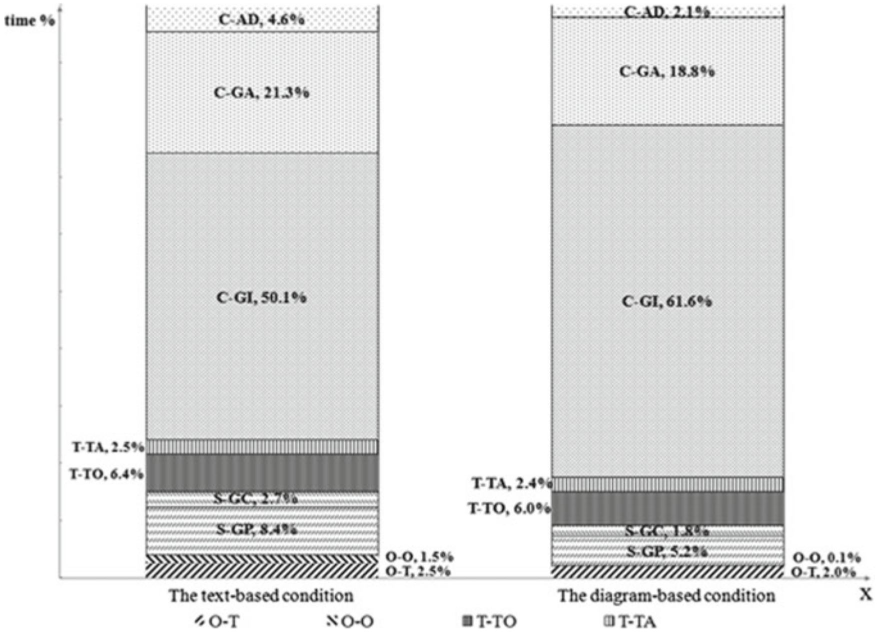


Fig. 7 Percentage of learning time for the groups engaged in different types of learning events in case 2

shown in Fig. 7, the clearest differences concerned cognitive-related learning events (C-). In DT, students invested more time here (82.5% for C-GI, C-GA, and C-AD) than did TT (76.0%). Within which, 61.6% of time was invested in group-individual learning activity (C-GI) in the DT condition, which was much longer than that in TT (50.1%). It means that groups in DT engage more percentage of time into the learning events building their understanding of learning materials collaboratively in the predesign interface of learning tool. In addition, comparing the percentage of time invested in social-related learning events (S), the groups in DT engaged for less time (7.0%) than those in TT (11.1%). Groups in DT specifically invested less time in the learning events of group planning (S-GP, 5.2%) and group monitoring (S-GM, 1.8%) than those in TT (S-GP, 8.4% and S-GM, 2.7%, respectively). It means that groups in DT invested less effort in the social interaction which is not helpful to the construction of knowledge schemata because there are no to-be-learned materials involved during these learning events. Therefore, the above findings indicate that the integration of the semantic diagram tool can mediate the flow of the interaction between students in groups. It decreased the percentage of learners' engagement in the social-relational learning events, but increased the percentage of learners' engagement in the cognitive-related learning events.

6 Conclusion

From the two cases, it can be found that the integration of semantic diagram tool in problem-solving project can transform classroom ecology. In the first case, the finding suggests that the integration of semantic diagram tool can make the class-level learning activity more student-centered and also promote teachers to change their teaching behaviors from knowledge transfer to knowledge facilitator in the classroom. In the second case, the finding suggests that the integration of semantic diagram tool can make the students in groups engage into cognitive-demanding learning activity more often, which can stimulate effective learning outcome at high likelihood. Therefore, we can conclude that semantic diagram tool is a suitable learning technology that can transform the classroom ecology. It can mediate the flow of interaction between teacher and students, and also mediate the flow of interaction between students in groups.

This finding can provide new insights for researchers to promote pedagogy innovation in the traditional Chinese classroom ecology by integrating semantic diagram tool. For example, we can use the semantic diagram tool as an initiator in the teacher development program to detect and help them change their traditional teacher belief and teaching behavior in the classroom. From case 1, we researchers co-designed the perfect problem-solving project with experienced teacher. If teacher has different experience and different teacher belief, the cases of CPS project integrated in semantic diagram tool would be different. From this point, how teacher organize the semantic diagram tool in problem-solving classroom can be used to detect the level of teacher's teaching skills. Based on the detected result, we can design targeted teacher training program to facilitate teacher's teaching skills. Our future study will focus on researching the issue. What's more, the finding in the second case provides us new research points for future study. For example, we found that semantic diagram tool helps group learners engaging in cognitively demanding learning activities, such as co-constructing group understanding and reviewing and commenting on the artifacts of peers, which is called "silent collaboration" (Caballero et al., 2014). However, we found that students in group did not make high-quality discussion based on the generated learning artifact. Therefore, it is worth to explore how to stimulate and promote high-quality group discussion based on the visualized learning artifact on the semantic diagram tool. It can help us refine the design of learning technology, such as semantic diagram tool.

Acknowledgements The manuscript is supported by the Humanity and Social Science Youth Foundation (Humanity and Social Science) Ministry of Education of China under Grant No.17YJC880001. We would like to thank all the people who prepared and revised previous versions of this document.

References

Baker, M., Andriessen, J., Lund, K., van Amelsvoort, M., & Quignard, M. (2007). Rainbow: A framework for analyzing computer-mediated pedagogical debates. *International Journal of Computer-Supported Collaborative Learning, 2*(2–3), 315–357.

Caballero, D., Van Riesen, S. A., Álvarez, S., Nussbaum, M., De Jong, T., & Alario-Hoyos, C. (2014). The effects of whole-class interactive instruction with single display groupware for triangles. *Computers & Education, 70,* 203–211.

Cai, H., Lin, L., & Gu, X. (2016). Using a semantic diagram to structure a collaborative problem solving process in the classroom. *Educational Technology Research and Development, 64*(6), 1207–1225.

Chen, B. B., & Li, D. (2008). Effect of classroom ecosystem on children's prosocial behavior. *Advances in Psychological Science, 16*(05), 733–739. (in Chinese).

Chen, M. H., Zhang, J., & Lee, J. (2013). Making collective progress visible for sustained knowledge building. In N. Rummel, M. Kapur, M. Nathan, & S. Puntambekar (Eds.), *Proceedings of the International Conference of Computer-Supported Collaborative Learning: To See the World and a Grain of Sand: Learning Across Levels of Space, Time, and Scale* (pp. 81–88). Madison: International Society of the Learning Science.

Dillenbourg, P. (2013). Design for classroom orchestration. *Computers & Education, 69,* 485–492.

Dragon, T., Mavrikis, M., McLaren, B. M., Harrer, A., Kynigos, C., Wegerif, R., et al. (2013). Metafora: A web-based platform for learning to learn together in science and mathematics. *IEEE Transactions on Learning Technologies, 6*(3), 197–207.

Ertl, B., Fischer, F., & Mandl, H. (2006). Conceptual and socio-cognitive support for collaborative learning in videoconferencing environments. *Computers & Education, 47*(3), 298–315.

Gijlers, H., & de Jong, T. (2013). Using concept maps to facilitate collaborative simulation-based inquiry learning. *Journal of the learning sciences, 22*(3), 340–374.

Gu, X., & Quan, G. (2014). The literature review of visual knowledge representation and model by semantic diagram. *e-Education Research, 5*, 45–52. (in Chinese).

Harrer, A., Pfahler, K., De Groot, R., & Abdu, R. (2013, September). Research on collaborative planning and reflection–methods and tools in the metafora project. In *European Conference on Technology Enhanced Learning* (pp. 139–150). Berlin: Springer.

Jin, H., & Wong, K. H. (2010). Training on concept mapping skills in geometry. *Journal of Mathematics Education, 3*(1), 104–119.

Kim, A. H., Vaughn, S., Wanzek, J., & Wei, S. (2004). Graphic organizers and their effects on the reading comprehension of students with LD: A synthesis of research. *Journal of learning disabilities, 37*(2), 105–118.

Morgan, B., & Martin, I. (2014). Toward a research agenda for classroom as-ecosystem. *The Modern Language Journal, 98*(2), 667–670.

Novak, J. D., & Canas, A. J. (2008). *The theory underlying concept maps and how to construct and use them* (Technical report). Pensacola: Institute for Human and Machine Cognition.

Poole, M. S., & Holmes, M. E. (1995). Decision development in computer-assisted group decision making. *Human Communication Research, 22*(1), 90–127.

Prieto, L. P., Villagra´-Sobrino, S., Jorrı´n-Abella´n, I. M., Martı´nez-Mone´s, A., & Dimitriadis, Y. (2011). Recurrent routines: Analyzing and supporting orchestration in technology-enhanced primary classrooms. *Computers & Education, 57*(1), 1214–1227.

Slof, B., Erkens, G., Kirschner, P. A., & Helms-Lorenz, M. (2013). The effects of inspecting and constructing part-task-specific visualizations on team and individual learning. *Computers & Education, 60*(1), 221–233.

Somekh, B. (2007). *Pedagogy and learning with ICT: Researching the art of innovation*. Routledge.

Suthers, D. D. (2001). Towards a systematic study of representational guidance for collaborative learning discourse. *Journal of Universal Computer Science, 7*(3), 254–277.

Scheuer, O., Loll, F., Pinkwart, N., & McLaren, B. M. (2010). Computer-supported argumentation: A review of the state of the art. *International Journal of Computer-supported collaborative learning, 5*(1), 43–102.

Urie, B. (1979). *The ecology of human development: Experiments by nature and design*. Cambridge, MA: Harvard.

van Amelsvoort, M., Andriessen, J., & Kanselaar, G. (2007). Representational tools in computer-supported collaborative argumentation-based learning: How dyads work with constructed and inspected argumentative diagrams. *The Journal of the Learning Sciences, 16*(4), 485–521.

van Bruggen, J. M., Kirschner, P. A., & Jochems, W. (2002). External representation of argumentation in CSCL and the management of cognitive load. *Learning and Instruction, 12*(1), 121–138.

Vogel, F., Wecker, C., Kollar, I., & Fischer, F. (2017). Socio-cognitive scaffolding with computer-supported collaboration scripts: A meta-analysis. *Educational Psychology Review, 29*(3), 477–511.

Wang, M., Cheng, B., Chen, J., Mercer, N., & Kirschner, P. A. (2017). The use of web-based collaborative concept mapping to support group learning and interaction in an online environment. *The Internet and Higher Education, 34,* 28–40.

Wen, Y., Looi, C. K., & Chen, W. (2015). Appropriation of a representational tool in a second-language classroom. *International Journal of Computer-Supported Collaborative Learning, 10*(1), 77–108.

Wegerif, R., & Mansour, N. (2010). A dialogic approach to technology-enhanced education for the global knowledge society. In M. S. Khine & I. M. Saleh (Eds.), *New science of learning* (pp. 325–339). New York: Springer.

Wegerif, R., McClaren, B. M., Chamrada, M., Schreuer, O., Mansour, N., Miksátko, J., et al. (2010). Exploring creative thinking in graphically mediated synchronous dialogues. *Computers & Education, 54,* 613–621.

Weinberger, A., Ertl, B., Fischer, F., & Mandl, H. (2005). Epistemic and social scripts in computer-supported collaborative learning. *Instructional Science, 33*(1), 1–30.