Smart Computing and Intelligence

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Virtual, Augmented, and Mixed Realities in Education

Springer

Smart Computing and Intelligence

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Chapter 1
Introduction: Virtual, Augmented, and Mixed Realities in Education

Christopher J. Dede, Jeffrey Jacobson and John Richards

Keywords Virtual reality · Augmented reality · Mixed reality · Augmented virtuality Virtual environment · VR · AR · MR · VE · Cyberspace · Immersion Presence · Haptics · Constructivism · Situated learning · Active learning Constructionism · Education · Schools · Museums · Informal education Conceptual change · Adaptive response · Metaverse · 360 video · HMD CAVE · Dome · Cybersickness · Sensory conflict · Interactive · Interactivity Multiuser virtual environment · MUVE · Massively multiple online roleplaying game MMORPG · MMO · Avatar · Panoramic · Oculus rift · HTC vive Google cardboard · GearVR · 3D

1.1 Origin of This Book

We live at a time of rapid advances in both the capabilities and the cost of virtual reality (VR), multi-user virtual environments (MUVEs), and various forms of mixed reality (e.g., augmented reality (AR), tangible interfaces). These new media potentially offer extraordinary opportunities for enhancing both motivation and learning across a range

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of subject areas, student developmental levels, and educational settings. However, past generations of learning technologies have seldom fulfilled the promise they offered, because of shortfalls in orchestrating research, development, policy, practice, and sustainable revenue to achieve transformational change in education.

With the sponsorship of NetDragon Websoft, a Chinese gaming and education company, in January, 2017 the Immersive Learning Group at the Harvard Graduate School of Education, and the Smart Learning Institute at Beijing Normal University co-convened an invitational research workshop of research experts in immersive learning. Its goal was to describe the leading edge of research in this field, as well as to push forward the evolution of next-generation immersive learning experiences. This volume is based on chapters these experts presented at that workshop and later refined based on feedback from rich discussions among participants. Overall, the goal of the workshop and book is to develop a strategic vision for educational VR and immersive learning. This will include evaluations of long term potential and opportunities, as well as current problems and barriers. Further, the ideas in the book can inform a research and development agenda for the field. Achieving this agenda will require understanding and surmounting issues with implementation, as well as the development of testbeds at scale.

The discussion at the workshop was scholarly and sophisticated, since we are a select group of researchers deeply familiar with this field. However, this book is written to be accessible to a broad audience, since we want to reach a much wider spectrum of stakeholders in immersive learning: teachers, administrators, scholars, policy makers, instructional designers, evaluators, industry leaders.

Also, even experts are still refining their definitions of terms in this field. For that reason, we include a glossary towards the end of this book that provides our definitions as used to frame the workshop. However, the authors of each chapter may use somewhat different definitions and will describe why in their discussions.

1.2 A Brief History of Immersive Media in Education

Virtual Reality (VR) was invented in the 60s or 70s with the flight simulators developed by military aerospace, although they might be better described as Mixed Reality (MR). [The next section of this chapter provides detailed definitions for all these terms.] The advance of research on educational applications of VR has been uneven, with empirical studies rare (Jacobson, 2008, pp. 62–75). VR was shown to be very effective for learning procedural tasks, in which students learns a sequence of steps to accomplish a task requiring maneuvers in three-dimensional space. Examples include as operating a vehicle, fixing on a complex piece of machinery, and finding your way around an otherwise unfamiliar landscape. The scientific literature on this is vast, but it never found significant use in K-12 education, which tends to emphasize declarative knowledge, primarily facts and concepts. Also, until 2015 equipment of usable quality was unaffordable at scale in classroom settings.

In the early 2000s multi-user virtual environments (MUVEs) and augmented realities (AR) came on the scene, and soon educational research established their effectiveness for learning. Further, these technologies were affordable at scale. But again they did not penetrate the K-12 market, for reasons discussed in Richards' chapter.

Today, VR AR and MR are all flourishing in the consumer market. Google, Samsung, SONY, and Facebook all have Head Mounted Devices (HMDs) and were joined by a half dozen new devices at the 2017 Consumer Electronics Show. Pokemon GO© had 100 million downloads from its launch on July 6, 2016 through December, 2016 and has been earning over $10M per day on IOS and Google Play combined. After twenty-five years of educational research, the consensus of the participants at the conference was that the time has come for these new technologies to have a substantial impact in education.

1.3 A Conceptual Framework for VR in Education

Learning experiences designed to teach complex knowledge and sophisticated skills are often based on "guided social constructivist" theories of learning. In this approach, learning involves mastering authentic tasks in personally relevant, realistic situations. Meaning is imposed by the individual rather than existing in the world independently, so people construct new knowledge and understandings based on what they already know and believe, which is shaped by their developmental level, their prior experiences, and their sociocultural background and context (Palincsar, 1998). Instruction can foster learning by providing rich, loosely structured experiences and guidance (such as apprenticeships, coaching, and mentoring) that encourage meaning-making without imposing a fixed set of knowledge and skills. This type of learning is usually social; students build personal interpretations of reality based on experiences and interactions with others.

Immersive media have affordances that enhance this type of learning. Psychological immersion is the mental state of being completely absorbed or engaged with something. For example, a well-designed game in a MUVE draws viewers into the world portrayed on the screen, and they feel caught up in that virtual environment. The use of narrative and symbolism creates credible, engaging situations (Dawley & Dede, 2013); each participant can influence what happens through their actions and can interact with others. Via richer stimuli, head-mounted or room-sized displays can create sensory immersion to deepen the effect of psychological immersion, as well as induce virtual presence (place illusion), the feeling that you are at a location in the virtual world (see Slater's chapter for more details).

Three types of immersive interfaces underlie a growing number of formal and informal learning experiences:

- *Virtual Reality* (VR) interfaces provide sensory immersion, at present focusing on visual and audio stimuli with some haptic (touch) interfaces. The participant can turn and move as they do in the real world, and the digital setting responds to maintain the illusion of presence of one's body in a simulated setting.

- *Multi-user Virtual Environment* (MUVE) interfaces offer students an engaging Alice-in-Wonderland experience, going “through the screen” to a simulated setting in which their digital avatars convey psychological immersion in a graphical, virtual context. The participant represented by the avatar feels remote presence inside the virtual environment: the equivalent of diving rather than riding in a glass-bottomed boat.
- *Mixed Reality* (MR) interfaces combine real and virtual settings in various ways, to enable psychological immersion in a setting that blends physical and digital phenomena. For example, an outdoor augmented reality (AR) experience using mobile devices can superimpose information, simulations, and videos on a through-the-camera-lens view of natural phenomena (Dunleavy & Dede, 2013).

The range of options is complex, because new sub-types of VR, MUVEs, and MR are constantly emerging. Each has unique strengths and limits for aiding learning, so understanding how to choose the right medium for a particular educational situation is an important next step in realizing the potential of immersive media in learning. However, some aspects of immersive learning apply across all these media.

1.3.1 How Immersive Presence Enhances Motivation and Learning

Immersion in a mediated, simulated experience (VR, MUVE, or AR) involves the willing suspension of disbelief. Inducing powerful immersion for learning depends on designs that utilize actional, social, and symbolic/narrative factors, as well as sensory stimuli (Dede, 2009):

- *Actional Immersion*: Empowering the participant in an experience to initiate actions that have novel, intriguing consequences. For example, when a baby is learning to walk, the degree of concentration this activity creates in the child is extraordinary. Discovering new capabilities to shape one’s environment is highly motivating and sharply focuses attention.
- *Symbolic/Narrative Immersion*: Triggering powerful semantic associations via the content of an experience. As an illustration, reading a horror novel at midnight in a strange house builds a mounting sense of terror, even though one’s physical context is unchanging and rationally safe. Narrative is an important motivational and intellectual component of all forms of learning. Invoking intellectual, emotional, and normative archetypes deepens the experience by imposing a complex overlay of associative mental models.
- *Sensory Immersion*: This occurs when the student employs an immersive display, like a head-mounted display, a CAVE, or a digital dome. The display presents a panoramic egocentric view of some virtual world, which the student leverages to imagine him or herself to be there. This type of immersion has been

used extensively for vehicle training and other procedural learning applications. There is also solid evidence that it can advantage students who need to learn the declarative knowledge connected to three-dimensional structures (Salzman, Dede, Loftin, & Chen, 1999; Jacobson, 2011, 2013).

- *Social Immersion*: As discussed in Gardner's and Kraemer's chapters, rich social interactions among participants in a shared virtual or mixed reality deepens their sense of immersion. In the real world, we participate in shared processes of reasoning between people who leverage their environment to make decisions and get things done. To the extent that a virtual or partially virtual environment supports this, it draws the user in, makes him or her feel more a part of it.

Psychological immersion is achievable in any of these interfaces by design strategies that combine actional, social, symbolic, and sensory factors.

Immersion is intrinsically helpful for motivation and learning in some ways, but not necessarily useful in others. In mastering complex knowledge and sophisticated skills, students learn well in a Plan, Act, Reflect cycle (PAR), in which first they prepare for an experience that involves doing something they want to master, then they attempt that performance, and finally they assess what went well, what did not, why, and what they need to learn in order to execute a more successful repetition of the cycle. Immersion is great for the Act part of the cycle, but unless used carefully can interfere with the Plan and the Reflect parts of the cycle. This—and numerous other factors—make effective instructional design for immersive learning complex.

1.3.2 Situated Learning and Transfer via Psychological Immersion

The capability of VR, MUVE, and MR interfaces to foster psychological immersion enables technology-intensive educational experiences that draw on a powerful pedagogy: situated learning.

Situated Learning: "Situated" learning takes place in the same or a similar context to that in which it is later applied, and the setting itself fosters tacit skills through experience and modeling. For example, in a medical internship, both the configuration and the coordinated team activities in a hospital surgical operating room provide embedded knowledge.

Situated learning requires authentic contexts, activities, and assessment coupled with guidance from expert modeling, mentoring, and "legitimate peripheral participation" (Wenger, 1998). As an example of legitimate peripheral participation, graduate students work within the laboratories of expert researchers, who model the practice of scholarship. These students interact with experts in research as well as with other members of the research team who understand the complex processes of scholarship to varying degrees. While in these laboratories, students gradually move from novice researchers to more advanced roles, with the skills and expectations for them evolving.

Related to situated learning is embodied cognition, an instructional strategy that posits retrieving a concept from memory and reasoning about it is enhanced by creating a mental perceptual simulation of it (Barsalou, 2008). For example, research shows that second grade students who acted out stories about farms using toy farmers, workers, animals, and objects increased their understanding and memory of the story they read. Steps involved in a grounded cognition approach to learning something include having an embodied experience (which could be created by immersive interfaces), learning to imagine that embodied experience as a mental perceptual simulation, and imagining that experience when learning from symbolic materials.

Potentially quite powerful, situated learning is seldom used in formal instruction because creating tacit, relatively unstructured learning in complex real-world settings is difficult. However, VR, MUVE, and MR experiences can draw on the power of situated learning by creating immersive, extended experiences with problems and contexts similar to the real world. In particular, all three types of immersive interfaces provide the capability to create problem-solving communities in which participants can gain knowledge and skills through interacting with other participants who have varied levels of skills, enabling legitimate peripheral participation driven by social and collaborative interactions.

Situated learning is important in part because of the crucial issue of transfer.

Transfer: Transfer is the application of knowledge learned in one situation to another situation, demonstrated if instruction on a learning task leads to improved performance on a transfer task, typically a skilled performance in a real-world setting. For example, statistical reasoning learned in a classroom can potentially aid with purchasing insurance, or with gambling.

A major criticism of instruction today is the low rate of transfer generated by conventional instruction. Even students who excel in schooling or training settings often are unable to apply what they have learned to similar real-world contexts. Situated learning addresses this challenge by making the setting in which learning takes place similar to the real-world context for performance in work or personal life. Learning in well-designed digital contexts can lead to the replication in the real world of behaviors successful in simulated environments (Fraser et al., 2012; Mayer, Dale, Fraccastoro, & Moss, 2011; Norman, Dore, & Grierson, 2012).

Moreover, the evolution of an individual's or group's identity is an important type of learning for which simulated experiences situated in immersive interfaces are well suited (Gee, 2003; Turkle, 1997). Reflecting on and refining an individual identity is often a significant issue for students of all ages, and learning to evolve group and organizational identity is a crucial skill in enabling innovation and in adapting to shifting contexts. Identity "play" through trying on various representations of the self and the group in virtual environments provides a means for different sides of a person or team to find common ground and the opportunity for synthesis and evolution (Laurel, 1993; Murray, 1998). As discussed in Slater's chapter, immersion is important in this process of identity exploration because virtual identity is unfettered by physical attributes such as gender, race, and disabilities.

Another attribute that makes immersive learning different, and potentially more powerful than real world learning, is the ability to create interactions and activities in mediated experience not possible in the real world. These include, for example, teleporting within a virtual environment, enabling a distant person to see a real-time image of your local environment, or interacting with a (simulated) chemical spill in a busy public setting. Slater's chapter categorizes opportunities for learning in simulations of settings not possible in the real world. Jacobson's chapter addresses how to develop representations that are authentic for learning.

All these capabilities suggest that, to maximize the power of immersive learning it's important not to present isolated moments in which VR, MUVEs, and AR are used to provide short-term engagement or fragmentary insight. Instead, extended experiences that immerse students in rich contexts with strong narratives, authentic practices, and links to real world outcomes are what truly unleash the transformational power of immersion. For example, while showing a 3-D model of a human heart illustrating blood flow is useful, immersing students in a virtual setting where they are applying knowledge of the heart to save the lives of computer-based agents is much more motivating, as well as effective in fostering a wide range of complex knowledge and sophisticated skills.

Schnieder references *constructivism* explicitly in his chapter, and the term is used widely in the educational VR literature. Constructivism is nearly the same thing as Situated Learning, because it revolves around a managed ecosystem within which students build their own learning experience.

1.3.3 Approaches to Designing Immersive Educational Media

1.3.3.1 Simulation

In this approach, the learning experience is an immersive simulation of an artifact, environment, or situation that exists in real life. For example, the phenomenon modeled at an appropriate level of fidelity for the instructional goals could be a virtual garden, or a simulated first-responder crisis with a building on fire, or a representation of some industrial process. Importantly, the simulation allows learners to do a few things they could not do in real life (National Research Council, 2011). For example, they could change the season of a virtual forest with the touch of a button, or move along a timeline for historical change, or operate dangerous machinery that would be too risky to learn how to use (at first) in real life.

In classroom settings, the instructional design is built around the simulation, with students often using a PAR cycle to interact with the simulation, complemented by the instructor teaching with knowledge and skills outside the simulation to aid in developing effective performances. The design of the curriculum in which the simulation is embedded is important, as is professional development for effective use of simulations in classrooms.

Some advantages of simulations are that they are quick to deploy, compared to developing more complex experiential environments, and relatively straightforward to understand. They are well suited for teaching students procedural knowledge, using skills to help them accomplish tasks that require some sequence of actions.

1.3.3.2 Constructionist Activities

In his chapter, Schneider discusses constructivism, the educational learning theory of which constructionism is one approach. Constructionist learning theory is based on the assumption that developing knowledge occurs best through building artifacts (physical or digital) that can be experienced and shared (Papert, 1991). In this type of learning, participants are given tools to build their own immersive environments, or provided an immersive environment and told to build something within it. In a classroom setting, an illustration would be a learning project where each student designs a “monster truck” for each one of the planets in our solar system, and then attempts to drive their truck on the surface of that planet. To be successful, they have to learn about that planet’s characteristics (e.g., gravity, temperature) and about the process of engineering a vehicle.

This approach can be very effective, because it empowers the learners to create something in which they have an emotional investment. Further, participants learn how to author in the immersive technology. As discussed later, all of the immersive technology manufacturers go to great lengths to develop tutorials and educational materials for people who want to informally create experiences that use their products. In formal education, all those materials can be leveraged in a constructionist curriculum. Further, research suggests that children can handle this approach at an earlier age than parents and teachers might expect.

As with simulations, in classroom settings the teacher must manage the learning process. She will need guidance in the technology itself and in instructional strategies, as well as a curriculum surrounding the building experience that is linked to academic objectives (Laurillard, 2009).

1.3.3.3 Embodied Cognition

As discussed earlier, embodied cognition learning experiences involving creating a mental perceptual simulation useful when retrieving a concept or reasoning about it (Barsalou, 2008). An embodied immersive experience via VR, MUVE, or MR can develop such a mental perceptual simulation, especially when facilitated by curricular and instructional support.

Embodied experience with academically important situations and phenomena is often limited, both by personal circumstances and by limitations of the real world. For example, an impoverished inner city student may never visit a farm, and no one now can have a physically embodied experience of living in the 17th century, or seeing relativistic effects when moving close to the speed of light. Digitally immersive learning experiences can bridge these gaps.

This approach to learning is not new; Montessori used analog artifacts as an important part of her pedagogical method. With the emergence of multi-modal interfaces that include gestures and similar physical movements, new forms of digitally enhanced embodied cognition are now possible and practical. Research on effective designs for immersive embodied learning is an exciting frontier for formal and informal education.

1.3.3.4 Directed Immersive Narrative

In this type of instructional design, learners participate in—and shape—a narrative. Participants are guided from beginning to end, but also choose their own path, with meaningful choices along the way to help them learn. In gaming, this type of immersive learning is usually a MUVE, although VR games are emerging. As discussed in Klopfer's chapter, the MUVE *The Radix Endeavor* is an example. However, such a learning experience could also include MR, if the phenomenon studied is some kind of activity that would make sense in a readily accessible type of physical environment, like an ecosystem. As discussed in Dede's chapter, *EcoMOBILE* is an augmented reality that illustrates this.

Directed narratives provide a superstructure within which the other types of immersive learning designs can be placed: simulations, constructionism (in part through the participant's choices), and embedded cognition. The story that emerges is the vehicle for identity and transfer that makes the whole more than the sum of its parts.

Transmedia narratives are emerging as a new form of entertainment and learning. Such a narrative can span immersive and non-immersive media, creating "alternate realities" that interweave fact and fiction to form myth. In education, the challenge is to immerse participants in the alternate reality for learning, but then fade its attraction so they return to the real world empowered through what they now know and can do.

1.3.3.5 Learning Simpler Material

This discussion has focused on learning complex knowledge and sophisticated skills, but what is the role of immersion in learning simpler, foundational material? It may seem counterintuitive given prevalent educational practice for centuries, but basic ideas are best learned in the context of attempting a relatively complicated task that is engaging and has relevance to the real world. Learning involving rote performances and low-level retention (e.g., math facts, vocabulary words) is not intrinsically interesting, and many students quickly tire of music, animations, simple games, and other forms of extrinsic rewards (the chocolate-covered broccoli problem). This leads to apathy about mastering foundational content and skills, especially when they have no perceived relevance to the learner's life. This motivational problem is exacerbated by a fundamental assumption of behaviorist instructional design that no complex knowledge or skill is learnable until the student has mastered every simple, underlying sub-skill. This tenet leads to long initial sequences of low-level teaching by telling and learning by listening, followed by rote practice with extrinsic bribery to keep going. In this common situation, students often lose sight of why they should care about learning the material, which may seem to them remote from the eventual goal-state of an engaging, complex knowledge or skill with real-world utility.

Substantial theory, research, and experience documents that—in contradiction to behaviorist theories of learning—students can master simple skills in the context of learning a complex task that is engaging and relevant to them (Dede, 2008). In contrast to conventional practice now, even when learning foundational material, students will experience higher motivation and longer retention of simple skills learned via the types of simulations, constructionist experiences, and directed immersive narratives discussed above. While learning by guided social constructivism seems inefficient compared to direct instruction, because more time is required, in the long run this approach is more effective, because less re-teaching is required due to problems with retention as un-engaging material is memorized, immediately tested, then forgotten.

So, if one is using such an approach to foundational learning, what is the role of immersion for the parts of instruction that involve simple skills and knowledge? While the psychological aspects of immersion are always useful in learning, sensory immersion in VR is necessary only for material that is intrinsically 3-dimensional (e.g., understanding the role of the ecliptic plane in the solar system) or where embodied cognition is useful (e.g., becoming an animal to experience its relationship to an ecological niche). 2-D simulations, non-immersive constructionism, and non-digital narratives—even rote teaching and learning—may be as effective and more efficient than immersive media if used for foundational learning in the context of a guided social constructivist experience.

1.4 Overview of the Chapters

The book begins with this introductory chapter introducing terms and conceptual frameworks, as well as providing a quick summary for the contents of each chapter, grouped into two types of discussions. *Frameworks* for the design and implementation of immersive learning are delineated in chapters by Slater; Jacobson;

Kraemer; Shute, Rahimi, and Emihovich; Richards; and Liu and Huang. Then, *Case Studies* of immersive learning are described in chapters by Dede, Grotzer, Kamarainen, and Metcalf; Gardner and Sheaffer; Klopfer; Johnson-Glenberg; and Schneider. Finally, a concluding chapter summarizes cross-cutting themes and advances a proposed research agenda.

1.4.1 Frameworks for the Design and Implementation of Immersive Learning

Slater's chapter, Implicit Learning through Embodiment in Immersive Virtual Reality, presents a framework for understanding how VR results in the illusion of presence. The participant in a VR scenario typically has the illusion of being in the virtual place and, under the right conditions, the further illusion that events there are really occurring. Slater also describes a further illusion that can be triggered in VR, referred to as body ownership. This can occur when the participant sees a life-sized virtual body substituting her or his own, from first person perspective. This virtual body can be programmed to move synchronously with the participant's real body movements, thus leading to the perceptual illusion that the virtual body is her or his actual body. Slater surveys various experiments showing that the form of the virtual body can result in implicit changes in attitudes, perception and cognition, as well as changes in behavior. He compares this with the process of implicit learning and concludes that virtual body ownership and its consequences may be used as a form of implicit learning. He concludes by suggesting how the study of the relationship between body ownership and implicit learning might be taken forward.

Jacobson's chapter, Authenticity in Immersive Design, describes authenticity a concept found in both media design and educational design, usually as a quality needed for success. He develops a theory of authenticity for educational experiences with immersive media (VR, MR, MUVEs) to help educators and designers in this new field. In this framework, authenticity refers to the relationship between a truth and its representation, guided by a purpose; A representation or an experience is said to be authentic, when it successfully captures the fundamental truth of what we are learning. This framework provides a practical way to look at one key dimension of good educational design.

Kraemer's chapter, The Immersive Power of Social Interaction, reviews new technologies and their impact on learning and students' motivation. The main argument is that, in order to achieve immersion, social interactions should be fostered. Three technologies are discussed that either inherently draw on social interactions (pedagogical agents, transformed social interaction) or can be enriched by including collaborative learning elements (augmented reality). For each of the three technologies, a short overview is given on the state of current developments, as well as on results from empirical. Also, discussed is to what extent these developments have built on social interaction, how this usage might be extended and whether beneficial outcomes can be expected from increased usage.

The chapter by Shute, Rahimi, and Emihovich focuses on how to design and develop valid assessments for immersive environments (IEs), particularly those providing “stealth assessment,” an ongoing, unobtrusive collection and analysis of data as students interact within IEs. The accumulated evidence on learning thus provides increasingly reliable and valid inferences about what students know and can do across multiple contexts, for both cognitive and non-cognitive variables. The steps toward building a stealth assessment in an IE are presented through a worked example. The chapter concludes with a discussion about future stealth assessment research, how to move this work into classrooms to enhance adaptivity and personalization.

Shifting from the design focus in prior chapters to implementation issues, Richard’s chapter summarizes the distribution and availability of the infrastructure needed for using VR and MR in the schools. Using immersive media requires a technology infrastructure consisting of dependable high-speed Internet connectivity to the classroom, a ratio of at least one-to-one computer to student, an interactive white board, and curriculum materials that can be monitored and controlled by the teacher. This infrastructure, the Digital Teaching Platform, is quickly becoming a reality. However, a larger and more complex barrier remains: integrating the new technologies with existing classroom systems and with existing and emerging pedagogical practice. The evolving nature of digital curricula, formative assessment, and classroom practice impact how teachers will be able to integrate these new technologies. Richards also addresses how immersive media can work as supplemental digital materials for instruction and assessment. In particular, he focuses on issues of the sensory comfort and fidelity of interaction, as these impact the viability of these technologies in the classroom.

Liu and Huang provide the last chapter in this section, The Potentials and Trends of Virtual Reality in Education. This presents an overview of virtual reality research in education, including a bibliometric analysis to evaluate the publications on virtual reality from 1995 to 2016, based on the Thomson Reuters’s Web of Science (WoS). A total of 975 related documents were analyzed based on their publication patterns (documents types and languages, major journals and their publications, most prolific authors, most productive journals and their publications, and international collaborations). Bibliometric results show that the number of article has been increasing since 1995 exponentially. USA, UK, and Chinese Taipei are the top 3 most productive countries/regions that are involved in virtual reality research in education. The findings can help researchers to understand current developments and barriers in applications of virtual reality to education.

1.4.2 Case Studies of Immersive Learning

The Framework chapters are followed by chapters presenting case studies of immersive media for learning. Virtual Reality as an Immersive Medium for Authentic Simulations, by Dede, Grotzer, Kamarainen, and Metcalf, describes a design strategy for blending virtual reality (VR) with an immersive multi-user virtual environment (MUVE) curriculum developed by the EcoLearn design team at Harvard University for middle school students to learn ecosystems science. The EcoMUVE Pond middle grades curriculum focuses on the potential of immersive authentic simulations for teaching ecosystems science concepts, scientific inquiry (collaborative and individual), and complex causality. The curriculum is inquiry-based; students investigate research questions by exploring the virtual ecosystem and collecting data from a variety of sources over time, assuming roles as ecosystems scientists. The implications of blending in VR for EcoMUVE's technical characteristics, user-interface, learning objectives, and classroom implementation are discussed. Then, research questions for comparisons between the VR version and the "Classic" version are described. The chapter concludes with generalizable design heuristics for blending MUVE-based curricula with head-mounted display immersion.

Gardner and Sheaffer's chapter, Systems to Support Co-Creative Collaboration in Mixed-Reality Environments, examines the use of mixed-reality technologies for teaching and learning, particularly for more active and collaborative learning activities. The basis for this work was the creation of the MiRTLE platform—the Mixed Reality Teaching and Learning Environment. They report on some of the lessons learnt from using this platform on a range of different courses and describe how different active/collaborative approaches were used. They also provide evidence of the effect of these different approaches on the overall student attainment and discuss the implications on the use of this technology, describing some of the technological research being done to develop these mixed reality learning spaces and the affordances offered by this approach. Finally they reflect on the tensions between the pedagogy and technology and consider the implications for the wider systems that support teaching and learning and co-creative collaboration in mixed-reality environments.

Klopfer's chapter, Massively Multiplayer Online Roleplaying Games and Virtual Reality Combine for Learning, argues that the way Virtual Reality (VR) can really make a difference in learning are involve bringing a truly unique experience to students. The simulated online world of games is an ideal genre for this, because these games provide a set of structures that not only scaffold learners in solving complex problems, but also provide a great deal of freedom to explore personally interesting pathways. In particular, Massively Multiplayer Online Roleplaying Games (MMOs) offer an environment that supports social learning and exploration around increasingly challenging problems. VR can greatly enhance MMOs through opportunities for more natural and expressive communication and collaboration, as well as ways to visualize the complex information resulting from interactions in this space. When this approach is applied in an educational context, learners can be presented with challenging problems, requiring participation from multiple players around realistic scientific concepts. As this genre moves forward, it can explore interesting hybrid approaches that combine VR with Augmented Reality (AR) and traditional displays to meet the needs of schools, teachers, and learners.

Johnson-Glenberg's chapter, Embodied Education in Mixed and Mediated Realities, provides a summary of some of this lab's immersive media and embodied STEM learning research. This synthesis focuses on the integration of gesture in learning, and a new gesture-based assessment. A taxonomy for embodiment in education is included. The chapter concludes with several design principles that the Embodied Games Lab has culled over the years while creating educational content that maximizes the affordances of virtual and mixed reality technologies and meshes those with best pedagogical practices.

Schneider's chapter, Preparing Students for Future Learning with Mixed Reality Interfaces, explores how new learning environments, such as mixed reality interfaces (i.e., interfaces that combine physical and virtual information), can prepare students for future learning. He describes four controlled experiments in which students learned complex concepts in STEM via a Tangible User Interface that created a "Time for Telling". This is followed by a summary the findings from this research, a discussion of the possible mechanisms for the effects found in those studies, and a suggestion of design guidelines for creating this type of constructivist activities. He conclude by discussing the potential of mixed reality interfaces for preparing students for future learning.

Following these sections on Frameworks and Case Studies, a concluding chapter summarizes cross-cutting themes and advances a proposed research agenda. The book ends with a glossary of terms related to immersive learning.

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Dr. Jeffrey Jacobson, Ph.D., has investigated fully immersive virtual reality (VR) as a learning medium for two decades, developing the technology and conducting experimental research. His early technical work in affordable free software is widely cited in the literature. His experimental trials on VR verses desktop displays were one of the few successful media comparison studies ever conducted. His later work (NSF and NEH funded) is highly regarded among scholars of cultural history and heritage. He has given hundreds of talks and demonstrations at top universities, academic conferences, and industrial conventions. Today, Dr. Jacobson is a co-founder and leader BostonVR, the fifth largest VR meet-up group in the world. He is currently consulting with educators and professionals in several industries, including university graduate studies, architectural design, large-vehicle piloting, and virtual reality display.

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John was President of the JASON Foundation, and GM of Turner Learning–the educational arm of CNN and the Turner Broadcasting System. Over the years, John has served on boards for a variety of education groups including NECC; Cable in the Classroom; Software Information Industry Association (SIIA), Education Market section; and the Association of Educational Publishers (AEP). John's projects have won him numerous awards including two Golden Lamps and several CODIEs, as well as several EMMY nominations. He is a respected keynote speaker, has been responsible for the publication of over 1000 educational products, and is the author/editor of over 100 chapters and articles, and four books, including Digital Teaching Platforms, Teacher's College Press (with Chris Dede). He is the primary author of the Software and Information Industry Association's annual U.S. Educational Technology Market: Pre K-12 report.

Part I
Frameworks for the Design and Implementation of Immersive Learning

Chapter 2
Implicit Learning Through Embodiment in Immersive Virtual Reality

Mel Slater

Abstract Virtual reality (VR) typically results in the illusion of presence. The participant in a VR scenario typically has the illusion of being in the virtual place, and under the right conditions the further illusion that events that are occurring there are really occurring. We review how these properties are useful for the application of VR in education. We present a further illusion that can be triggered in VR referred to as body ownership. This can occur when the participant sees a life-sized virtual body substituting her or his own, from first person perspective. This virtual body can be programmed to move synchronously with the participant's real body movements, thus leading to the perceptual illusion that the virtual body is her or his actual body. We survey various experiments that show that the form of the virtual body can result in implicit changes in attitudes, perception and cognition, and changes in behavior. We compare this with the process of implicit learning and conclude that virtual body ownership and its consequences may be used as a form of implicit learning. We conclude by suggesting how the study of the relationship between body ownership and implicit learning might be taken forward.

Keywords Virtual reality · Education · Implicit learning · Embodiment
Body ownership

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2.1 Introduction

In this article we consider how Immersive Virtual Reality may be useful for implicit learning, that is acquiring knowledge and skills without conscious effort, or without explicitly having to learn specific information. First, we briefly recap what virtual reality is (see also Chap. 1) and some essential concepts, then we review virtual reality in education and implicit learning, and go on to provide some examples of how it has been exploited to bring about changes in people. Note that for the purpose of this article we extend the notion of implicit learning to mean accomplishing changes to the self that were not explicitly programmed, including changes in attitudes, behaviors and cognition.

2.1.1 Immersive Virtual Reality

Some background and history of Virtual Reality (VR) is discussed in Chap. 1 of this book, and further information and discussion of a range of applications is presented in (Slater & Sanchez-Vives, 2016). VR incorporates participants bodily into a virtual computer-generated world. A critical aspect is that as the participant turns or moves his or her head the computer updates the images displayed at a very high frame rate, ideally at least at 60 Hz. The participants therefore become immersed in a completely surrounding virtual environment that they see when turning in any direction with movement and motion parallax, and they perceive this (ideally) in a wide field-of-view display. (The same can be done with spatialized sound.) A way to grasp the difference between VR and other media comes from noting that in VR we can go into a virtual movie theatre and watch a movie. We can enter a virtual living room and watch a virtual TV. We can sit by a virtual computer and play a computer game—all while in virtual reality. In fact in VR we can even simulate the process of entering into a VR and thus enter realities within realities (Slater, 2009). There is no other technology that has ever enabled this.

2.1.2 Presence—Place Illusion and Plausibility

The fundamental experience that VR delivers is referred to as 'presence'. This is the perceptual illusion of being in the place rendered by the VR system. Presence in virtual environments was first elucidated in a set of papers in the early 1990s and there followed many years of further research into this concept reviewed in (Sanchez-Vives & Slater, 2005). Presence was deconstructed into two independent concepts in (Slater, 2009), referred to as *Place Illusion* (PI) and *Plausibility Illusion* (Psi). PI refers to the original idea of the illusion of being in the virtual place. It was argued that a necessary condition for this illusion is that the virtual reality is perceived through natural sensorimotor contingencies, a theory referred to as the active vision paradigm (O'Regan & Noë, 2001). This argues that we perceive through using our whole body, via a set of implicit rules involving head turning, leaning, reaching, looking around, bending an ear towards, and so on. The illusion of 'being there' can be generated to the extent that the VR system affords perception through natural sensorimotor contingencies. The argument is that if we perceive using the same methods in an environment as we normally perceive, then we must be in that environment, this being the simplest hypothesis for the brain to adopt.

Place illusion is the first effect of viewing a scene with a VR display. However, the Plausibility Illusion (Psi) is the illusion that the events experienced in VR are really happening (even though the participant knows that they are not). Psi requires that the virtual environment respond to actions of the participant, generates spontaneous actions towards the participant, and is ecologically valid when the environment is meant to depict real-life events. For example, when the environment includes virtual human characters, they should acknowledge the presence of the participant (e.g., by gaze) and respond to the participant's actions (e.g., by maintaining appropriate interpersonal distances).

When both PI and Psi operate then participants are likely to behave realistically in the VR. This has far reaching consequences. For example, VR has been used extensively for psychological therapy for 25 years. This is only possible because patients exhibit sufficient affect in VR as to enable the clinicians to engage in the therapeutic process.

2.1.3 Embodiment and Body Ownership

A participant in a VR wearing a HMD looking in any direction would always see only the virtual world. What happens when the participant looks down towards his or her own body? If it has been so programmed then they would see a virtual body substituting their own. This virtual body would be life sized, approximately occupy the same space as where the person feels their real body to be, in other words be coincident in space with the real body. The body would be seen from first person perspective, i.e., from the eyes of the virtual body providing the centers of projection from which the participant sees the virtual world.

Seeing the virtual body from first person perspective is already a cue to the brain that it is the person's actual body, thus providing an illusion towards this effect. The illusion is enhanced if further multisensory feedback is applied. This follows from the fundamental finding reported in the rubber hand illusion. Here a person seated by a table has their real (say right) hand resting on the table but hidden behind a screen, and a right-handed rubber arm placed in an anatomically plausible position on the table in front of them, as if it were their real arm. Typically the hidden real arm and the rubber one are approximately parallel. The experimenter touches both the rubber hand and the hidden real hand synchronously so that the person sees the touches on the rubber hand but feels them on their real hand (Botvinick & Cohen, 1998). After a few seconds of such stimulation proprioception shifts to the rubber hand, so that although the person knows for sure that it is not their real hand, it feels as though it is. When the seen and felt touch are asynchronous then the illusion typically does not occur. Petkova and Ehrsson (2008) applied a similar technique to the whole body, to produce a full body ownership illusion. In this case a stereo camera was mounted on the head of a manikin pointing down towards its body, and the video streamed to a person wearing a stereo HMD. Provided that the person was looking down towards their real body, it would seem to them that their real body had been substituted by the manikin body. The experimenter synchronously tapped the abdomen of the manikin body (which would be seen through the HMD by the participant) and the abdomen of the person. Thus the person would see the manikin body being touched while feeling this on their real body, and integrate the two percepts into one overall illusion that the manikin body was their body. As with the RHI when the manikin body was threatened with a knife the participants exhibited an increase in physiological arousal concomitant with the attack. A synchronous tapping did not lead to these illusions.

It was demonstrated in (Slater, Perez-Marcos, Ehrsson, & Sanchez-Vives, 2008) that an equivalent to the RHI could be achieved in VR, where the person saw a virtual arm protruding from their shoulder, that was seen to be tapped by a virtual ball, that was in fact controlled by a tracked wand touching their corresponding real hand. Slater, Spanlang, Sanchez-Vives, and Blanke (2010) showed that a body ownership illusion could be attained over a virtual body, and that the dominant factor was seeing the body from first person perspective, although visuotactile synchrony also contributed.

Transformed body ownership was first tried in the very early days of VR in the late 1980s, although not as scientific research and therefore not published at the time. Lanier (2006) later reported that at VPL, the company he led, in the late 1980s and early 1990s they experimented with embodying people as virtual lobsters, and used unusual combinations of human muscle movements as a means by which people could move their lobster limbs. He termed this ‘Homuncular Flexibility’, meaning that humans can quickly adapt to new bodies and new modes of bodily control.

For the sake of terminology we refer to *embodiment* as the process by which the person’s body is substituted by a virtual one—using the head-tracked stereo head-mounted display, motion capture to track the person’s real movements and map these to movements of the virtual body, or tactile stimulation on the person’s body synchronous with virtual objects seen to touch the virtual body. Hence embodiment refers to the actual setup, whereas ‘body ownership’ refers to the perceptual illusion that the virtual body is the person’s own body (even though of course they know that this is not the case). Later we will be discussing the consequences of such virtual body ownership for implicit changes.

2.2 Learning

2.2.1 Intentional Learning

As we have seen earlier VR has been developed, used, and studied for the past 25 years and there have been many applications in education. For recent reviews see (Freina & Ott, 2015). There are at least five reasons why VR may contribute to education: (i) Transforming the abstract to the concrete; (ii) Doing rather than only observing; (iii) The infeasible or impossible becomes practical; (iv) explore manipulations of reality; (v) go beyond reality to positive advantage. We consider each in turn. This section is based on (Slater & Sanchez-Vives, 2016).

2.2.1.1 Transforming the Abstract to the Concrete

VR can transform abstractions into concrete perceptions and experiences. Hwang and Hu (2013) used VR and showing that it is advantageous compared to standard paper and pencil techniques in the learning of mathematics. Learning concepts about vector algebra and spatial abilities was described by Kaufmann, Schmalstieg, and Wagner (2000) using an HMD based augmented reality system. Roussou (2009) used a 'virtual playground' for the teaching of mathematics by 50 eight to twelve year olds, where children watched a virtual robot illustrating concepts leading to enhanced enjoyment, better conceptual understanding, and reflection.

2.2.1.2 Doing Rather Than Observing

In general VR supports 'doing' rather than only observing. This is very important for example in neurosurgery training—e.g. (Müns, Meixensberger, & Lindner, 2014)—or any kind of 'hands on training', especially that is too problematic or dangerous to rehearse in reality.

2.2.1.3 Doing the Infeasible or Practically Impossible

VR can be used to carry out activities that may be infeasible in reality. A good example here is learning geography, geology or archeology, where students would typically be unable to visit real places, but could instead visit them virtually. This idea of virtual field trips—e.g. (Lin et al., 2013)—has become popular and certainly feasible inexpensively with today's relatively low cost hardware.

2.2.1.4 Manipulating Reality

Einstein's famous thought experiment about riding on a light beam can become a concrete experience in VR. How would the world be if gravity were changed by a fraction? How would it be like to play football in such a world? The theories of relativity can be modeled and experienced in VR. Such ideas were propounded and implemented by Dede, Salzman, Loftin, and Ash (1997). These ideas are worth following up, since manipulating the parameters of reality is, course, not possible in reality, but in VR this is possible.

2.2.1.5 Beyond Reality

VR is often thought of as a way to simulate and reproduce reality—for example, visit ancient archaeological sites such as Qumran as part of a history lesson (Cargill, 2008), or manipulate parameters of reality as discussed in the previous section. However, it is possible also to go quite beyond what is possible in reality in unexpected and radical ways. For example, Bailenson et al. (2008b) showed how teaching can be transformed where every student in a shared VR perceives that she or he is the center of attention of the teacher through placement in the classroom and through eye gaze feedback.

Generally with regard to VR and learning Fowler (2015) points out that too much emphasis has been placed on the technical affordances of VR (such as providing an immersion in a 3D space) and not enough on the pedagogical aspects of using VR. In particular VR applications must address (i) how the VR experience advances explanation; (ii) deepening understanding, for example, through exploration; (iii) taking account of the wider social context involved in learning. Any system that uses VR cannot escape demonstrating how these three required properties are satisfied. In the next section we consider, however, an entirely different approach that, it could be argued, obviates the need for such classifications, since the aim is learning, but not explicit learning. Moreover, all of the above examples rely essentially on the presence inducing aspects of VR: they transform learners to another world, and make use of the properties and affordances of that world for some type of learning. Instead we consider a more radical approach that while still necessitating presence also relies on body ownership.

2.2.2 *Implicit Learning*

Implicit learning is the process whereby individuals learn complex information unconsciously and gain abstract knowledge through this process (Reber, 1989). It has been applied, for example, to the learning of artificial grammars (Reber, 1967) where subjects are exposed to grammatically correct sentences over a set of symbols and asked to reproduce them while receiving feedback about which were correct or incorrect, without reasons why. There is no explicit learning of rules, and yet subjects are able to pick up the grammar after several such exposures. In particular subjects are able to correctly infer information about novel stimuli (Reber, 1989). However, they may not be able to explicitly articulate the complex rules that they have learned.

Seger (1994) argued that implicit learning satisfies several criteria: (i) subjects are not conscious of what they have learned and as mentioned above cannot articulate it; (ii) the information learned is complex in the sense that it is not simply based on correlations or counts of frequencies; (iii) the learning gained is not based on hypothesis testing or explicitly trying to find patterns, but essentially people acquire information incidentally through other cognitive processes than those that might be employed through explicit, deliberate and directed learning. Since people with amnesia apparently do as well on implicit learning as others, the neural basis of such learning is quite different from that involved in tasks based on episodic memory. A meta analysis of implicit learning in amnesic patients was carried out by Kessels and Haan (2003). The neural basis of implicit learning is reviewed in (Reber, 2013). Implicit learning is typically robust in the sense that the learning does not fade over time, for example Agus, Thorpe, and Pressnitzer (2010) showed how newly acquired sound patterns would be retained for weeks. A meta-analysis has also been shown that people with autism spectrum disorders do well on implicit learning (Foti, De Crescenzo, Vivanti, Menghini, & Vicari, 2015).

Apart from the obvious example of language, implicit learning is important for such skills as surgery (Masters, Lo, Maxwell, & Patil, 2008), where was found that learning by observation and without explicit verbal instruction produced results that were particularly useful in the multi-tasking environment of a surgical operation. In a similar vein Vine, Masters, McGrath, Bright, and Wilson (2012) showed that gaze strategies of experts could be learned implicitly in the training of laparoscopic skills, similar to a result that had earlier been shown using VR (Wilson et al., 2011). Bailenson et al. (2008a) showed how implicit learning of motor tasks (Tai Chi) exploiting VR could be accomplished. This also involved observation—of a self-avatar seen from third person perspective and in a mirror, of recorded movements of themselves and a teacher. The affordances offered through stereoscopy outweighed viewing the same movements on a video with respect to ultimate performance. Also using VR (Bell & Weinstein, 2011) showed how people with psychiatric disability would improve their job interview skills by taking part in a simulated job interview. Pan, Gillies, Barker, Clark, and Slater (2012) report an experiment where males who are socially anxious about meeting women learn to reduce their anxiety after a conversation with a virtual woman, that intersperses mundane conversation (e.g., what work do you do?) with more personally alarming discussion (e.g., do you have a girl friend?), even though there was no explicit attempt at all to influence the participants in this direction. It as if the participants incidentally learned through the mundane conversation that there was nothing to fear from such an interaction, and then were able to carry this learning over to the more personal aspects of the conversation at a lesser level of anxiety.

In all of the above examples the information to which people were exposed was directly related to what was being implicitly learned: to implicitly learn a grammar subjects were exposed to sentences, to implicitly learn Tai Chi or surgery subjects observed examples. In the next Section we move on to a quite different form of implicit learning—where the stimuli are not related to what is being learned except in a quite indirect manner.

2.3 Implicit Change Through Virtual Body Ownership

2.3.1 The Proteus Effect

In Sect. 2.1.3 we introduced the concept of virtual body ownership, the perceptual illusion that a virtual body coincident in space with the person's real body will be perceived as their own body. Here we examine the consequences of such transformed body ownership.

The first work on these lines was by Yee and Bailenson (2007) who introduced what they termed the 'Proteus Effect'. (In modern parlance we might refer to the god Proteus as a 'shape shifter'.) Their observation was that the appearance and actions of a person's digital self-representation in both online non-immersive environments and in VR affects their behavior. For example, they showed that people in a collaborative VR moved closer or not to virtual representations of others depending on whether the face of their own virtual body was judged more or less attractive than their real one. People with taller virtual bodies were more aggressive in a negotiation task than people with shorter bodies. A similar result has been reported by Freeman et al. (2013) in a study of paranoia—that people seeing the virtual world from a taller perspective (without actual embodiment in a virtual body) were more confident in being with others than those with a point of view that was shorter.

Groom, Bailenson, and Nass (2009) used the Proteus Effect to examine racial bias. In the context of a simulated job interview they embodied White people in a Black virtual body that they saw reflected in a virtual mirror for 1 min in a HMD, with visuomotor feedback restricted to head movements. A racial Implicit Association Test (IAT) (Greenwald, McGhee, & Schwartz, 1998) showed that there was greater bias in favor of White after the embodiment.

The Proteus Effect is explained by Self Perception Theory (Bem, 1972) where it is argued that people will infer the attitudes of others from inferring their behavior in a situation, and also apply the same to themselves—i.e., infer their own attitudes by inferring this from their own behavior. Yee and Bailenson (2007) also argue that there is a stereotyping effect, that people behave in a situation according to how others would expect a person with such a body to behave. These theories might explain the racial bias results of Groom et al. (2009) since participants were placed in a social situation (a job interview) where racial bias is known to operate.

However, it would not explain results where there is no social context and there are no behavioral demands on participants—they simply observe their own virtual body from first person perspective or in a mirror. Most importantly they cannot explain changes that occur as a result of embodiment that would not be expected to be associated with transformed body ownership, or which are not under the control of participants. For example, it has been observed that the RHI results in a cooling of the associated real hand (Moseley et al., 2008), and Salomon, Lim, Pfeiffer, Gassert, and Blanke (2013) showed that this applied to the whole virtual body.

2.3.2 The Multisensory Framework

In the multisensory framework people see their virtual body from first person perspective usually with another type of sensory input consistent with the virtual body being their own. This may be visuotactile stimulation, where objects seen to touch the virtual body trigger corresponding feelings of touch on the real body (as in the RHI), or visuomotor synchrony, where through real-time motion capture the virtual body is programmed to move synchronously and in correspondence with real body movements, or both (Kokkinara & Slater, 2014).

Theoretical underpinnings of body ownership have been formulated by Blanke, Slater, and Serino (2015). This includes (i) multisensory integration of proprioception, (ii) top-down body-related visual information in peripersonal space, (ii) embodiment in the sense we have described above. These requirements are clearly satisfied with virtual embodiment that includes first person perspective and visuomotor synchrony. It was further argued in (Banakou & Slater, 2014), that since whenever in our whole lives we have looked down towards ourselves we have seen our body. Moreover, in normal healthy conditions whenever we move our limbs we see them move. There is therefore, in the context of virtual embodiment, overwhelming evidence that when there is embodiment with first person perspective and visuomotor synchrony that the simplest perceptual hypothesis for the brain to adopt is that the virtual body is our own body, irrespective of how much it looks like our body or not. As has been empirically found in the Proteus Effect sometimes this change of body carries with it other changes at the attitudinal, behavioral, physiological, and cognitive levels.

In a study of racial bias Peck, Seinfeld, Aglioti, and Slater (2013) embodied light-skinned females (15 per group) in either a dark-skinned virtual body, a light-skinned one, a purple one, or no body. The body in all cases was seen directly from first person perspective and in a virtual mirror, and with visuomotor synchrony. Those in the 'no body' group saw a reflection at the geometrically correct place in the mirror, but with visuomotor asynchrony. Prior to the experiment the racial IAT was administered, and again after the experiment. The period of embodiment was about 12 min, during which time participants were only required to move and look towards their body, and 12 virtual characters, half of them Black and half of them White walked past. It was found that there was a decrease in IAT indicating a reduction in implicit racial bias only for those who had been in a light-skinned body. That a few minutes embodied in a Black virtual body could reduce implicit racial bias seemed unlikely, however, using only a black rubber arm in the RHI, Maister, Sebanz, Knoblich, and Tsakiris (2013) found a similar result. In a subsequent study Banakou, PD, and Slater (2016) again embodied 90 White female participants in a White or Black body. Each had 1, 2 or 3 exposures with visuomotor synchrony following the movements of a virtual Tai Chi teacher. However, the IAT was administered first one week before the initial exposure, and one week after the final exposure. It was again found that those in the Black virtual body showed a clear reduction in implicit bias, independently of the number of exposures, whereas this did not occur for those in the White virtual body. This indicates that the reduction in racial bias may be sustained, and that a single exposure is sufficient for this.

The above relates only to implicit attitudes, however, changes have been found due to embodiment in other domains. Kilteni, Bergstrom, and Slater (2013) embodied 36 people in one of two different bodies: 18 in a body resembling Jimi Hendrix (dark skinned, casually dressed) and the rest in a formally dressed light-skinned body. Their task was to play hand drums. The virtual hand drums were registered in space with real hand-drums. There was visuomotor synchrony since participants would see their virtual hands moving with their real hand movements, both directly and in a mirror, and visuotactile synchrony since as their hand was seen to touch the virtual drums they would feel this because their real hand would simultaneously strike the real drum. Through real-time motion capture the extent to which participants moved their upper body was recorded (they were seated with their legs holding the drums in place). It was found that those in the more casual, dark-skinned body exhibited much greater body movement than those in the formal light-skinned body. Participants had no idea about the purpose of the experiment, since it was between-groups and therefore they could not know about the other type of body used.

The drumming example is concerned with behavioral change. However, strong perceptual changes can also be induced with transformed body ownership. van der Hoort, Guterstam, and Ehrsson (2011), using the technique of streaming video data to an HMD, embodied people in a Barbie doll body or a giant manikin body. This was used together with synchronous visuotactile stimulation. They observed that in the first case subjects overestimated object sizes and in the second case underestimated. Banakou, Groten, and Slater (2013) took this one step further using virtual embodiment to show that the *form* of the body and not just the size influences this perceptual result. Adult participants were embodied either the body of a child of about 5 years old or in an adult shaped body but shrunk down to the same size as the child. Visuomotor synchrony was used in addition to seeing the body from first person perspective and in a mirror. The same result was found, that on the average participants in these small bodies overestimated object sizes. However, the degree of overestimation of those in the child body was around double that of those in the shrunk down adult body. Moreover using an IAT that tested between self-attribution of child-like or adult-like attributes, those in the child body condition self attributed more towards the child-like than the adult-like. In another condition that used visuomotor asynchrony all these differences disappeared.

Our next example illustrates a cognitive change. Participants were asked to explain a pressing personal problem to a character on the other side of a virtual room (Osimo, Pizarro, Spanlang, & Slater, 2015). They were embodied in a virtual body that was a very close likeness of their real body. The virtual person to whom they explained their problem (referred to as the Counselor) was either a virtual rendition of Dr. Sigmund Freud, or another copy of themselves. After explaining their problem they were shifted to the body of the Counselor and saw and heard their initial incarnation explaining the problem. Then as the Counselor they could reply back to themselves offering advise as to how to resolve the problem, after which they were re-embodied back in their original body as themselves, and saw and heard (with a disguised voice) a replay of the advice of the Counselor (in fact their own advice). They could keep swapping back and forth between self-embodiment or embodiment as the Counselor hence maintaining a conversation. Therefore this setup was an objectification of 'talking to oneself' except that the 'one' spoken to was represented as a virtual person. In each embodiment the participant would see their virtual body directly from first person perspective and in a mirror. The conditions of the experiment were that the Counselor was a copy of themselves or of Freud, and that as Counselor they experienced visuomotor asynchrony or synchrony. It was found that although in all conditions there was an improvement in the rating of their mood in relation to the person problem, the best improvement was when they were embodied as Freud with visuomotor synchrony. This produced a strong level of body ownership and agency with respect to the Freud body. In other words being embodied as Freud gave them access to different mental resources, allowing them to better able move towards a solution to their problem, than being embodied as another copy of themselves.

In the next section we consider these findings in the context of implicit learning.

2.3.3 Embodiment and Implicit Learning

All of the above examples show how transformed body ownership can lead to changes. Although this was not the goal of those studies, for the purposes of exposition we can reformulate them as 'learning' studies. For example, to learn how to show less racial bias in an IAT, to learn how to resolve a personal problem through talking to different representations of yourself, to learn how to play the drums with greater vigor.

In Sect. 2.2.2 we saw that there are a number of criteria that implicit learning has to satisfy: what is learned is non-conscious, it is complex, it is not as a result of hypothesis testing, and it is not based on episodic memory. If we take the racial bias as an example, there is no conscious attempt in the procedure to influence implicit racial bias. In fact participants in these between-group experimental designs only experience one body type. What is being learned is complex—an IAT is a complex response-time based procedure. There is clearly no hypothesis testing or deliberate attempt to learn something based on episodic memory. People simply have an experience.

In these cases the effects are implicit, but the information that generates the implicit changes is seemingly quite different from implicit learning. For the latter the data for learning is directly and closely related to what is to be learned—e.g., sentences generated by a specific grammar. In the case of body ownership the information is only indirectly related. In the self-talk example—the self-conversation with Freud—no coaching whatsoever was given about how to address personal problems in a more productive way.

Our hypothesis is that simply having experiences from another perspective embodied in another body results in implicit change. When the body is related to an 'issue' (e.g., racism) then the change will be within that domain, even though there is no explicit information whatsoever about racial bias in the experience. This also conforms to the view of Gallagher (2005) who discusses the relationship between body and mind. When the type of body conforms to what is to be learned then this will aid learning over and above what can be learned through explicit learning.

2.4 Summary

This paper has reviewed the major concepts of virtual reality, in particular presence (the illusion of being in the virtual place, and the illusion that events there are really happening) and also how virtual reality can be used to produce virtual body ownership—a virtual body coincident in space with the real body and seen from first person perspective can generate the illusion that it is the person's body. We have reviewed how presence has been used in education, and also discussed the notion of implicit learning. Our discussion then led to the observation that virtual body ownership can lead to implicit changes, so that, for example, when a person embodies a body of different race their implicit bias against people of that race may decrease. This is similar to what happens in implicit learning, even though the approaches are quite different. We then reached the conclusion that learning may be enhanced when participants are embodied in a virtual body that is appropriate for that type of body. For example, someone learning how to be an orchestra conductor might best be embodied in the body resembling, for example, Leonard Bernstein; learning opera Luciano Pavarotti or Maria Callas; or learning ballet Natalia Osipova. This remains an interesting hypothesis to test with controlled experimental studies.

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Chapter 3
Authenticity in Immersive Design for Education

Jeffrey Jacobson

Abstract *Authenticity*, is a concept found in both media design and educational design, usually as a quality needed for success. Here, we develop a theory of authenticity for educational experiences with immersive media (VR, MR, MUVEs, etc.) to help educators and authors in this new field. In our framework, authenticity refers to the relationship between a *truth* and its *representation*, guided by a *purpose*. By truth, we refer to a fact, concept, or procedure, about something in the world or in the body of human knowledge, something we want to learn. To scaffold the learning process, students require a representation of the thing. It may be a written article (for concepts), an image (e.g., a photograph), or maybe an exemplar (an idealized example of a category). A representation or an experience is said to be authentic, when it successfully captures the fundamental truth of what we are learning. The immersive media have unique capabilities and just in the last few years have become available to the public on a large scale. Our theory is not a comprehensive style guide, but a practical way to look at one key dimension of good educational design.

Keywords Authenticity · Elegance · Pedagogy · Design · Immersive · VR

3.1 Introduction

In this chapter, we develop a theory of *authenticity* as an essential quality of educational experiences with immersive media (VR, MR, MUVEs, etc. see Chap. 1). We produced it to be an analytical tool for educators and designers, to help them build effective experiences for their students. It is not a comprehensive style guide for authoring, but illustrates a crucial dimension of good design. It will help with the lack of guiding theory in education in immersive media (Fowler, 2015).

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In our framework, ***authenticity*** refers to the relationship between a *truth* and its *representation*, guided by a *purpose*. By *truth,* we refer to a fact, concept, or procedure, about something in the world or in the body of human knowledge, something we want to learn. To scaffold the learning process, students require a *representation* of the thing. It may be a written article (for concepts), an image (e.g., a photograph), or maybe an exemplar (an idealized example of a category).

A **representation** or an **experience** is said to be authentic, when it successfully captures the fundamental *truth* of what we are learning. For example:

> Suppose we create an animated 3D model of a bird design to help us to teach the flight dynamics of its species. In that case, the representation does not need to be highly detailed —a simple, flexible, 3D model will do, as long as its proportions are right (Fig. 3.1).
>
> However, the movement of that model must very accurately depict the movements of a real bird of that type. On the other hand, if the goal is to learn exactly what that bird looks like (feathers, beak, skin, etc.) then the representation must have a lot of physical detail, but its motion would not be relevant. It may not need to move at all (Fig. 3.2).

Importantly, authenticity is **not** realism. Usually, a representation is said to be more *realistic* the better it mimics the real thing in every way. Sometimes, that is what we need for authenticity, but more often, we do not need it.

In our discussion, we will call this the principle of *truth* (Sect. 3.3.1), that the relevant facts or ideas are represented in the virtual environment depicted by the immersive medium. However, we must understand the purpose of the learning experience to know which truth we are trying to represent (Sect. 3.3.1). Further, we strive for the right *level of detail* (Sect. 3.3.2), meaning that the representation shows what it needs to show, but without extraneous detail. Finally, the design should be *elegant* (Sect. 3.3.3), meaning that the different representations in the design fit together and function well.

Fig. 3.1 Artful model of a bird, low resolution, but well proportioned. Suitable for animation to demonstrate movement. http://clipart-library.com/clipart/XrcjKGXTR.htm

Fig. 3.2 High resolution drawing of a bird, suitable for study of detail. http://clipart-library.com/clipart/ATbr7BLRc.htm

But first, we will look at existing theories of learning in *educational* media, because the *purpose* comes from the learning objective and the pedagogies that help us get there. Specifically, immersive media is well suited to constructivist approaches, where students build their own learning experience within the learning environment as guided by the teacher (Duffy & Jonassen, 2013). Also, Winn's (2003) framework for learning in VR is an excellent tool to focus that approach. We will use both to guide our discussion.

Versions of the concept of *authenticity* is also found in writings throughout media design (Kronqvist, Jokinen, & Rousi, 2016), and in education (Strobel, Wang, Weber, & Dyehouse, 2013) (Herrington & Parker, 2013). We will explore those theories, describe our own frame with examples, and finally list the topics where immersive media are most likely to be useful (Sect. 3.6).

3.2 Existing Concepts of Authenticity and Learning

Good design in educational media a broad topic, and achieving high quality is usually more art than science. This leads authors to employ (and create) frameworks of design advice, to point out the key issues and provide practical ways to develop solutions. These guides are usually specialized by topic, media type, and purpose, although some can be quite broad. Others have a particular theme or theoretical approach. In this section we will look at some of the existing theories of authenticity and learning.

Kronqvist et al. (2016) define authenticity as a function of the degree of presence, affordance, and control the environment provides to the user. William Winn (2003) describes learning in VR as an adaptive response to a challenging task or environment. The learner is *embedded* in the virtual environment while s/he is *embodied* there. Both approaches apply reasonably well to the other immersive media. We also reference *constructivism*, which posits that the learner constructs his or her own learning experience, within the learning environment. Constructivism is the most widely cited pedagogical approach in the historical literature on educational VR (Duffy & Jonassen, 2013).

Then, we look at two theories of authenticity in education, one by Strobel et al. (2013) and another by Herrington and Parker (2013). Both frameworks emphasize the search for a way to convey the fundamental or foundational truth of the topic to the student in way that is respectful of the material. They also contain much practical advice, specific to their fields. We are fortunate to have their work, because the idea of authenticity is widely cited in the education literatures, but often without adequate definition or theoretical foundation (Strobel et al., 2013).

Readers who wish to go deeper should look at Barab, Squire and Dueber (2000) and their work on authenticity as an emergent property of good practice in training. Donnelly (2014) provides a practical design guide for authenticity in architectural design.

3.2.1 Kronqvist's Authenticity in Virtual Environments

Kronvqvist et al. (2016) created a metric for measuring *authenticity* in virtual environments, when accessed through a VR-like interfaces (e.g. HMD, or big screen). They developed a post-test questionnaire to measure it, across several types of interfaces. Their goal is to give VR researchers a way to verify that their virtual environments are sound.

They define *an affordance* to be a quality of the virtual environment (VE), which is the degree to which representations of (objects and phenomena) in the VE provide the same affordances as the real thing. It allows user to perform their learning tasks much as they would in real life. This implies that we must know what the *purpose* of the simulation is, in order to define *which* affordances should be captured. (See Slater's *Plausibility Illusion*, Chap. 2). That makes Kronqvist's *affordance* similar to our own definition of authenticity. However, his definition of authenticity includes the sense of *presence* in the user (equivalent to Slater's *Place Illusion*, Chap. 2), but our definition does not.

3.2.2 Winn's Framework for Learning in Sensorially Immersive VR

Winn's approach (Winn, 2003) states how authentic learning can work in an immersive environment, even though he did not use the word, *authenticity*. While his focus was on VR, the principles apply well to the other immersive media. He proposes that optimal learning requires (quote):

> ***Embeddedness:*** *The mental and physical tasks a person performs cannot be defined without some reference to the environment. This does not imply that the environment defines cognition, but that some reference to the environment is required to describe it.*
>
> ***Embodiment****: The learner/actor's physical body is an essential part of the process, because everything we perceive must be mediated through our limited senses. We directly use our bodies to accomplish most tasks and the brain must be regarded as an organ of the body.*
>
> ***Dynamic Adaptation:*** *In a changing environment, we must continually adapt to the changing circumstances. It is also true that the environment changes in response to the person's actions. In this way the individual and his or her environment are evolving together, responding to each other.*

Embeddedness would certainly apply to many or most immersive learning environments, especially those with high authenticity. The **embodiment** clause requires an engaging physical environment, a good mixed reality, or a fully immersive virtual reality. In Slater's terms (Chap. 2) embeddedness requires what he calls *place illusion*, and dynamic adaptation requires what he calls *plausibility illusion*, as well as an instructional strategy. Slater's chapter also explores embodiment.

However, Winn's framework is only partial, with respect to the overall enterprise of educating and learning. For example, it does not address assessment, which should be hidden within the learning activities and the environment itself (Shute et al., Chap. 5; Dede, 2012) to avoid distraction from the learning task.

3.2.3 Constructivism in VR for Education

Ideally, learning as an active process, which the student constructs within the learning environment, to achieve the required goals, and complete the learning task, all under the teacher's supervision. This is the *constructivist* approach to learning theory, which is widely cited in the literature on educational immersive media. Describing it further is beyond the scope of this chapter, but we recommend (Duffy & Jonassen, 2013) for a good description. Also, Gardner and Sheaffer (Chap. 9) and Shute et al. (Chap. 5) discuss constructivism in their chapters.

3.2.4 Strobel's Framework for Authenticity in Engineering Education

Strobel et al. (2013),[1] distills the idea of authenticity found in the literature on education for engineering. The consensus, there, is to bring the learner closer to the realities of the workplace, with principles, summarized here:

> **Context Authenticity**: *Context resembles real-world context [....]*
>
> **Task Authenticity:** *Activities of students resemble real-world activities [....]*
>
> **Impact Authenticity:** *Student work is utilized in out-of school situations [....]*

Srobel proposes two more dimensions that come from the Applicative or Sociocultural Perspective:

> **Personal Authenticity:** *projects are close to students' own life. (i.e. life-stories of their neighborhood, biodiversity in the forest nearby)*
>
> **Value Authenticity:** *personal questions get answered or projects satisfy personal or community needs.*

They recommend that learning environments should have the above characteristics, and others not included in our summary.

3.2.5 Herrington's Framework for Authenticity

Herrington, Reeves and Oliver (2009, p. 17) propose a framework of authentic e-learning, summarized, here:

- *Provide authentic contexts that reflect the way the knowledge will be used in real life.*
- *Provide authentic activities.*
- *Provide access to expert performances and the modeling of processes.*
- *Provide multiple roles and perspectives.*
- *Support collaborative construction of knowledge.*
- *Promote reflection to enable abstractions to be formed.*
- *Promote articulation to enable tacit knowledge to be made explicit.*
- *Provide coaching and scaffolding by the teacher at critical times.*
- *Provide for authentic assessment of learning within the tasks.*

They recommend that learning environments have the above characteristics, and others not included in our summary.

[1] Strobel relies heavily on theories by Anderson, Billet, and Buxon, and cites them properly. We do not have the space to repeat those citations, here.

3.3 Our Framework for Authenticity in Educational Immersive Media

In this chapter, we develop our theory of *authenticity*, as a way to think about the design of immersive educational experiences. It is centered on the idea that for a simulation or representation to be authentic, it must capture the basic truth of what it represents. However, you also have to know what the instructional goal of the experience is, before you can decide what truths you want to represent.

Herrington et al. (2009), Herrington and Parker (2013), Strobel et al. (2013), Kronqvist et al. (2016) each place the same requirement on their definitions of authenticity. However, Kronqvist's definition of authenticity is broad, including *presence* for authenticity in immersive media, which we do not. Strobel's authenticity includes design advice for education in engineering, and Herrington's authenticity does the same for e-learning.

Our theory of authenticity is meant to be a helpful tool for designers and users of immersive educational experiences, but not a comprehensive guiding theory. Instead, we propose authenticity as **one dimension** of good design, one tool among several. The key components are:

- **Purpose**
- **Truth**
- **Elegance**
- **Continuity**

We will describe these, in turn, and how they work together. Then, we will discuss where authenticity resides and how to measure it.

3.3.1 *Purpose and Truth*

As with so many endeavors, it begins with the *purpose*, our learning goals, which drive everything else in the design. Generally, we want successful *transfer*, where the student learns something from the immersive media that s/he successfully applies elsewhere (Grotzer et al., 2015). The most straightforward examples are simulations, like this one:

> A good way to begin learning how to drive a car is to use a driving simulator. There, the student pilots a virtual automobile through increasingly challenging lessons. The virtual car must behave like a real one, and have realistic controls, to support the training. However, neither the virtual car nor the virtual environments has to look good. Even relatively crude models will do, as long as they are correctly proportioned and readable (Fig. 3.3).

This illustrates how *purpose* defines the next component of our framework, which we call the *truth*. That is the relationship between the real thing and its

Fig. 3.3 Driving simulator (Teen Driver Source, Children's Hospital of Philadelphia). http://www.teendriversource.org/images/drivingsimulator.jpg

simulation in the virtual environment. We want the simulation to capture or represent some fundamental truth about the real thing.

> In our driving simulator example, the need to learn how to drive dictates which aspects of the car we want to simulate. If, instead, we wanted to teach the student how to decorate a car, we wouldn't care much about how the simulation behaves, only how it looks.

This applies to experiences, not just objects. For example:

> Suppose the student is using a VR simulation to overcome a fear of public speaking. S/he sees herself in an auditorium room filled with automated human figures (*bots*). At the simplest level, she speaks for a set period of time, giving a short speech, while the virtual audience either sits in silence or responds in a positive or negative way. After each interval, the student provides feedback to the software indicating her level of discomfort and her desire to continue. Based on the curriculum built into the software, the student is progressively challenged with an increasingly difficult audience (Pertaub, Slater, & Barker, 2002) Fig. 3.4.

> In this case, the bots only need to be recognizably human, capable of expressing emotion through simple facial expressions or even body language, alone. This requires that their motions be authentic in terms of what they convey, but the actual appearance of their bodies can be quite simple. In the physical world, puppeteers use this to great effect (Engler & Fijan, 1997).

Fig. 3.4 Two audience reaction scenarios presented by a VR trainer for public speaking (Pertaub et al., 2002). https://publicspeaking.tech/wp-content/uploads/2016/11/Pertuab_etal_PublicSpeakingAnxiety.jpg

The learning experience is effective if it induces the required feelings of discomfort, and provides the student with the opportunity to overcome it. It is *authentic* if it is well focused on the lesson, and only the lesson, in an elegant way. The *truth* in the above example is that public speaking won't hurt you, the *representation* is the audience and its reactions, and the *purpose* is to overcome one's fear of speaking.

See Kraemer (Chap. 4) for a deeper exploration of how students can learn from virtual social immersion with sophisticated bots and avatars. In Sect. 3.4, we will discuss where authenticity resides, and how to measure it, but first, we will complete the description of our framework.

3.3.2 Level of Detail

In every media, the author chooses which *level of detail* is most appropriate for his or her purpose. S/he may present a large number of details in order to convey complex information, create a mood, build an argument, or for other reasons. For example, a scientific visualization may require complex forms to represent the data fairly. On the other hand, certain traditional Japanese paintings convey a great deal of information with just a few clean lines. Also, a high level of detail is not the same thing as realism. Many representations that are not realistic have a lot of detail in them, while some realistic depictions don't need much detail.

Usually, an element will belong in the design, because:

- It conveys something about the topic to be learned. (For example, if the topic is chemistry, we might see models of molecules.)
- It makes the experience more aesthetically pleasing, even if the author is not explicitly making art.
- It helps the experience function.

For example, a student might be using a mixed reality program to examine (representations of) different species of frog. The command s/he uses to switch from one representation to another doesn't represent anything, but it is essential for the process.

Here is an example that illustrates some of these themes:

The Virtual Ancient Egyptian temple (Gillam & Jacobson, 2015, Chaps. 3 & 7) (Fig. 3.5) was built to be a symbolic representation of a late period cult temple. Our virtual temple had the minimum architectural features required to properly house a representative sample of Egyptian ceremonies and public events. The temple also contains hieroglyphics and artwork on the walls, arranged in the correct order, saying the right things, to typify an ancient Egyptian temple.

The virtual temple (minimally) embodies the key characteristics of late period Egyptian cult temples, but not a particular one. It is an *exemplar,* an idealized model used to describe a category of things (Barsalou, 1992). Had we faithfully simulated one particular, real, temple, its idiosyncratic features would have misled our readers into thinking they were universal. Instead, a less realistic, idealized, temple is paradoxically a better exemplar.

However, we did add some naturalistic lighting and material effects, just to make the space more comfortable and readable. We also (unrealistically) enlarged the hieroglyphics to make them readable in the computer displays available at the time.

Level of detail can refer **to action and motion,** as well as the appearance of things. Japanese anime' often has only the most important elements in the scene moving, an example of minimalism in movement. In immersive media, especially VR, one must be careful to present enough motion in the virtual environment so it feels true to the things it depicts. But do not use so much motion that the user become disoriented, distracted, or annoyed.

Fig. 3.5 The Hypostyle Hall of the Virtual Egyptian Temple (Gillam & Jacobson, 2015). http://publicvr.org/images/HypostylePromoShot.jpg

3.3.3 *Elegance*

When the learner's experience is *elegant,* we mean that is achieves its purpose artfully, with the right level of detail. The experience is well integrated with its environment, well-coordinated with other instructional materials, internally consistent, sensitive to its audience, and consistent with it purpose. The narrative design must fit well within in the larger curriculum. (Dede (Chap. 8) and Schneider (Chap. 12) both discuss what stages of the student's learning process are more likely to benefit from immersive media and those that are not.)

> For example, the authenticity of any historical or archaeological digital simulation partly depends on how well it fits with other materials and media that describe the same thing.

In immersive media, the user's physical or pseudo-physical location in the virtual environment is a critical part of the narrative and usually is the foundation of how they interact with it. (See Winn's *embeddedness*, above).

In the mixed reality that Gardner and Sheaffer describe in Chap. 9, some of the students are in a physical space, while others are in a MUVE, but the two spaces are connected through a kind of portal wall. This allows the students "in" the MUVE to participate in the classroom activities sufficiently, so they apparently learn just as well as the students who are there, physically.

An elegant design should also exhibit *continuity* in its use of detail and other factors. We do not expect a written document to have too many different fonts. We do not expect a movie to speed up or slow down during the presentation, nor do we expect the picture quality to change abruptly. That is why most works of most media usually have a similar level of detail throughout; but there can be exceptions, if skillfully handled. For example, there may be some moment or object in the representation that is rendered at a deliberately higher or lower level of detail, specifically to focus attention, create a mood, or convey information.

Two excellent examples of elegance in authentic design are the mixed realities of Johnson-Glenberg (Chap. 11) and Schneider (Chap. 12). In both cases, they add just enough virtualized information for a profound impact, exploiting the advantages of mixed reality (MR). They take it a step further by designing unique and tangible interfaces that embody the information the student must learn and the action s/he must take to do so.

Elegance is not *minimalism*. The idea behind minimalism is to use as few elements as absolutely possible to achieve the purpose in the simplest way. This is a valid design choice, but an elegant design does not have to be so strict. It may contain more elements than necessary for aesthetic or functional reasons.

Suppose you want to show medical students what it is like to be in a hospital operating room during a surgery. An example of the type is shown in Fig. 3.6 (Kapralos, Moussa, & Dubrowski, 2014).

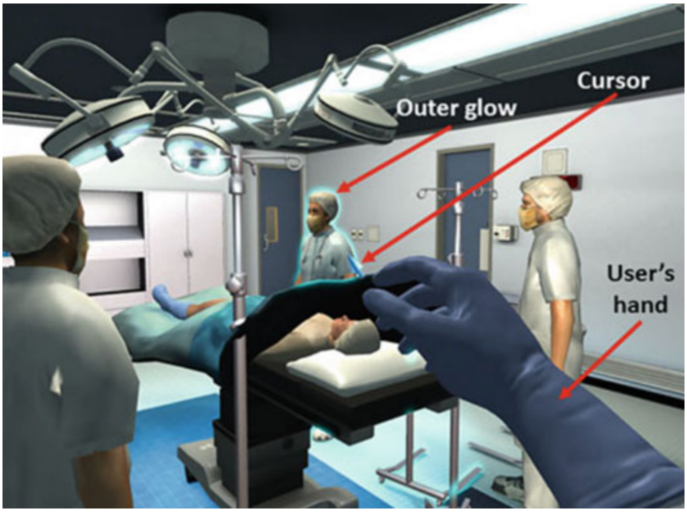

Fig. 3.6 VR simulation of a hospital operating room with user interaction (Kapralos et al., 2014)

> Suppose further that the student could take on the role of a nurse or doctor. If the goal of the simulation is to teach operating room procedure, then it must accurately show those procedures. That would require only a moderate level of detail in the models, the virtual people, and how they move.
>
> However, *additional* details might create a more comfortable experience and help the user focus. For example, the simulated people, the patient, the doctor, and staff, should all look a little different, which is more information for the system to implement. But if everyone in the room were identical, it would be distractingly strange.

Another aspect of *elegance*, is that the student should have a seamless and comfortable experience. Ideally, nothing should distract them, like motion sickness, which happens in VR, if it is not handled properly. See Richards (Chap. 6). Also, Shute et al.'s stealth assessment methods (Chap. 5) would be very useful, because they afford a way to test the student's knowledge, but without interrupting their experience in the virtual environment—an elegant solution.

3.4 Where Does Authenticity Reside and How Do We Measure It?

Authenticity resides in both the system (the virtual environment and its interface) and within the mind of the user. Simply put, if the builder of the virtual environment has created a representation that expresses the learning objective (a truth) successfully, then the student will perceive that truth and be able to interact with the representation productively.

Ideally, the ultimate test would be whether the student could demonstrate knowledge transfer, from the learning experience to a genuine situation in real life. However, the history of educational innovation is littered with examples of students learning despite technology or regardless of it. Additional measures are needed to determine the value and authenticity of the virtual environment.

Fortunately, there are many test instruments available for educational media and immersive media that should be directly useful. But we cannot propose a generic measure for authenticity, based on our theory alone. To evaluate some learning experience for authenticity, we'd also have to know it's base media (VR, MR, or MUVE), it's topic, and much more about its structure. What we can do is discuss basic approaches.

One way to measure authenticity would be to embed measures integral to the virtual environment and the experience, itself. We would be interested in whether the student perceives the truths we want the representations to convey. Shute's *stealth assessment* techniques could be quite useful here (Chap. 5). Slater (Chap. 2) does something similar in his tests for *presence*.

One could also measure how authentic the immersive learning environment is, outside of its educational mission, using something like the instrument in Kronqvist et al. (2016). However, he also measures *presence*, which our definition of authenticity does not include. We treat presence (Slater, Chap. 2) as a different dimension of immersive design, which exists alongside authenticity.

Finally, one could examine an educational immersive experience, and see how well each element works and how well they all work together. Hopefully, they will perform their key functions and represent the key facts in an elegant way, so the student can focus on the learning task. In the case of virtual objects, we expect them to behave like the real thing. Kronqvist et al. (2016) call these *affordances*.

3.5 Handling Uncertainty

Immersive media always use 3D models for objects and (in VR and MUVEs) the environment itself. That creates difficulty for the author, when s/he needs to express uncertainty or competing ideas about what things should look like. People tend believe what they see, so they often look uncritically at immersive representations. Usually, the author and the user, both want as much detail as possible in the simulation, but to depict what *is* known, one often must complete the picture with elements are partly speculation. Otherwise, the virtual environment won't be useable. Examples:

> Imagine a simulation of a crucial historical event, like the battle of Gettysburg in the US Civil war (Fig. 3.7). We know the basic clothing the soldiers wore, their weapons, the terrain, and much about the battle itself. But there are many gaps in our understanding. *Exactly*, how many soldiers were here or there? How much of the fight was in the town, and how much was outside of it?
>
> If the simulation is to show individual soldiers, at any level of detail, the author must show them moving about the battlefield. Without any other knowledge, the viewer cannot tell how much of that comes from established historical fact verses the artist's need to complete the environment. But without a complete environment, the immersive medium can't function.
>
> Another example: what happens when one attempts to simulate a building that is known to be a fully enclosed space, but the character and placement of an entire wall is not known? The author has no choice but to put something in there, which amounts to an educated guess, because leaving a gap would be worse.

A corollary problem is how to handle competing theories of how something should be represented.

> For example, an archaeologist may discover evidence of what appears to be a single building. While assembling the known elements, s/he may discover that some of the archaeological evidence conflicts with other clues. Or the total evidence does not make sense when used together in one building. A possible explanation is that the observed evidence comes from more than one building. They may have existed in the same location, but at different time periods.
>
> One strategy for the instructor would be to represent each competing theory its own 3D model, and let the students explore them. Sometimes, the competing models can be overlaid to occupy the same space, for easier comparison.

Fig. 3.7 Simulation of the battle of Gettysburg. Not from an immersive application, but illustrative. http://www.scourgeofwar.com/index.shtml

There are many visual techniques an immersive media designer could use to indicate uncertainty in parts of the virtual environment. S/he could indicate uncertain elements with a particular color, or lack of color, or lack of detail. S/he could use labels or symbols to explain the prominence of each virtual object. Many creative solutions are possible, but they'll have to be handled skillfully to preserve the system's *elegance.*

3.6 When to Use Immersive Media in Education

Like any other toolset, immersive media is good for teaching some topics and less effective for others. That begs the question: when is immersive media useful in industry and/or society? The gross outlines are fairly straightforward, from 60 years of experimentation with VR and other immersive media. However, the details are only just now being worked out, as the medium is adopted by society, generally. While the fundamentals of the technology have not changed, new applications are invented every day on a massive scale, because of a drastic drop in cost in just the last few years. (See Richards, Chap. 6). This will lead to both a steady evolution of the technology and occasional breakthroughs.

We list many good uses of immersive media, below, although it could never be an exhaustive accounting. Pantelidis (2010) also provides a good summary.

3.6.1 Training in Real Life Tasks

Many activities in real life do not employ immersive media, but immersive media could be used for training in those pursuits. These are usually activities that require *procedural* knowledge. Major examples are:

- Simulators of aircraft and other big dangerous machines. In fact, it was the military Aerospace industry that invented modern VR and they have a long track record of Success in training Airline pilots and military aviators.
- Military training has a long and productive history with VR and more recently MR.
- Medical training, through simulation, has been a huge area of research and development for years. Entirely physical props, mixed realities, and full VR are all being studied.
- Basically, learning how to do anything dangerous like firefighting, first responder to disasters, and So on.

Training is the oldest and most studied use for Virtual Reality, and the literature on it is vast.

3.6.2 Learning Topics Usually Taught in School

Many pursuits require knowledge about things, usually facts and concepts, such as history or physics. This is called *declarative* knowledge, which encompasses most of what one learns in school. Here are a few topics that require learning a large amount of declarative knowledge:

- Cultural history and heritage, where ancient monuments, events, and even whole societies can be simulated, interactively (Gillam & Jacobson, 2015).
  Bandt points out that aboriginal peoples Australia identified certain rock formations as having spirits and magical properties. Most of those formations have unique acoustical properties, so an immersive acoustical simulation of such as site would be informative. See http://www.sounddesign.unimelb.edu.au/site/NationPaper/NationPaper.html
- Astronomy, where students can explore the solar system, or reason about observable movements of objects in the sky (Vosniadou & Brewer, 1992).
- Physics, where students can see and interact with a variety of simulations (Shute & Ventura, 2013).

- Simulations of social situations, investigations, laboratories, and a much else using MUVEs (Dede, Chap. 8), (Kraemer, Chap. 4), and (Gardner & Sheaffer, Chap. 9).

Of the immersive media, MUVEs are most widely used and studied in education, and probably have the most uses. See Klopfer (Chap. 10) and Dede (Chap. 8).

3.6.3 Clinical Psychology

Years of productive research have gone into using VR for diagnosis and treatment of things like PTSD in adults, ADHD in children, and treatment of phobias.

> For example, most PTSD and phobia treatments center on gradual exposure to what the user fears, while keeping him/her physically safe. That helps them overcome their aversion, and work through their cognitive dissonance around similar situations (Fig. 3.8) (Rizzo, 2016).

A great deal of literature is available; we recommend a search on the work of Dr. Albert Rizzo (2016).

Fig. 3.8 Gradual exposure therapy to cure post-traumatic stress disorder (PTSD) (Rizzo, 2016). https://c1.staticflickr.com/8/7609/16983316895_5e8decce03_b.jpg

3.6.4 Training for Direct Use in Industry

There are many industries where immersive media are directly useful, and students will need training to use them well.

- When Mixed Reality reveals something not otherwise seen:
  - Internal anatomy during surgery or diagnosis.
  - Subsystems in existing buildings.
  - Internals of complex machinery during maintenance.
  - Threat factors in dangerous situations. For example Augmented Reality glasses could be used to see areas of dangerous radiation inside a nuclear power plant.
- When virtual reality can be used for collaborative or remote work:
  - Users can collaborate at a distance as they engineer some complex object via an immersive MUVE.
  - Collaborators coming inside a digital dome or CAVE for a design review of some artifact. This is more useful for structures one wants to be inside, such as a building (Jacobson 2011, 2013).
  - Orthoscopic surgery offers a kind of VR as the interface for the surgeon trainee.
  - An operator can use a VR-like interface to control a robot carrying out any number of types of missions.
- Building community and other social uses:
  - Entertainment, such as World of Warcraft and similar games with millions of users and complex social dynamics.
  - Remote meetings and socializing, as with Second Life, AltspaceVR and VR Chat.
  - Immersive news reporting can give the audience a much more powerful view of some faraway situation. Immersive film is being used to great effect here.
- Other uses:
  - First responders, security people and the military can use VR to learn the layout of a terrain before going there, physically.

3.6.5 When Not to Use Immersive Media

Usually, one should not use immersive media when some other media will do just as well or better. For example when one needs to understand the exterior of an object, a 3-D model visible on a computer monitor is adequate. Or when the information is abstract, such as budgets, data, music, and poetry. One could use abstract visualization to make three-dimensional visualizations, but then you have the problem of elements in the graph covering up (occluding) each other from the user's point of view. It should only be done for a specific reason that arises from the data itself. Last but not least, the expense and barriers to access to VR and MR remain significant for most k-12 schools, although that is changing (Richards, Chap. 6).

3.7 Conclusion

We live in an exciting and productive time. The mass availability of decent quality immersive media tools has led to an explosion of creativity across many industries, education not least (Richards, Chap. 1). The social learning process will require a great deal of trial and error, just as it does with individuals. And with each experiment, it is important that practitioners in education learn the right lessons. For some direct design advice, hard won through experience, see Johnson-Glenberg (Chap. 11) and Dede et al. (Chap. 8).

Guiding theory has an important role to play. Experimental science can provide the foundation for these theories, but practical advice must also be developed from experience. In this chapter, we developed a theory of authenticity in educational immersive media, as a means to understand this key feature of good design. It is not a comprehensive framework, but a dimension of design that touches all aspects of an immersive education. In future articles, we will look at practical applications.

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Author Biography

Dr. Jacobson has investigated fully immersive virtual reality (VR) as a learning medium for two decades, developing the technology and conducting experimental research. His early technical work in affordable free software is widely cited in the literature. His experimental trials on VR verses desktop displays were one of the few successful media comparison studies ever conducted. His later work (NSF and NEH funded) is highly regarded among scholars of cultural history and heritage. He has given hundreds of talks and demonstrations at top universities, academic conferences, and industrial conventions. Today, Dr. Jacobson is a co-founder and leader BostonVR, the fifth largest VR meet-up group in the world. He is currently consulting with educators and professionals in several industries, including university graduate studies, architectural design, large-vehicle piloting, and virtual reality display design. All this work is described in his many scientific publications and two books. Dr. Jacobson has served as a project reviewer for the National Science Foundation, NOAA, NASA, and many academic publishers. He is currently the CEO of EnterpriseVR (http://enterprisevr.com), his consulting firm.

Chapter 4
The Immersive Power of Social Interaction

Using New Media and Technology to Foster Learning by Means of Social Immersion

Nicole C. Krämer

Abstract The chapter reviews new technologies and their impact on learning and students' motivation. The main argument is that in order to achieve immersion, social interactions should be fostered. Therefore, three technologies are discussed which either inherently draw on social interactions (pedagogical agents, transformed social interaction) or can be enriched by including collaborative learning elements (augmented reality). For each of the three realms, a short overview on the state of current developments as well as on empirical studies and results is given. Also, it is discussed to what extent they built on social interaction, how this might be extended and whether beneficial outcomes can be expected from this.

Keywords Immersion · Pedagogical agents · Augmented reality
Transformed social interaction · Collaborative learning · Social interaction

4.1 Introduction

Recent years have seen the development of new and affordable Virtual Reality technology that is widely disseminated and especially made available for entertainment and leisure time use. For example, the WII uses video analysis to capture people's behavior and transfer it to virtual, animated worlds, Oculus rift allows to be immersed in 3D worlds and augmented reality games like Pokemon Go are played on every street. While the entertainment industry has grasped the potential and optimized the technology for leisure time use, applications targeted at educational use still have to catch up. It is, however, highly plausible to assume that these interactive technologies will also be beneficial in education. This is not only due to the fact that people experience fun when using these technologies which might lead

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to increased learning motivation, but they might have inherent benefits for learning applications. It has, for example, been described that augmented reality technologies which provide location-based virtual overlays in the real world enable learning at the exact right time and place (Bower, Howe, McCredie, Robinson, & Grover, 2014; Yuen, Yaoyuneyong, & Johnson, 2011). However, it is certainly not sufficient to simply bring these technologies to classrooms and other learning situations and to expect that they will (a) widely be used because of their popularity in other realms and (b) automatically lead to beneficial results. In parallel to their employment, the technologies need to be adapted to the educational goal and to be orchestrated in order to best enhance learning outcomes as well as motivation. Therefore, the developments need to be informed by relevant theories of learning so that they cannot only be immersive but also effectively shape the learning process (e.g., guided social constructivism, situated learning).

The focus within the present chapter will be on social aspects of learning and the question whether new immersive VR technologies can be used to foster learning via optimizing social interactions between teacher and learner or between learners in collaborative learning environments. In general, it aptly has been stressed that learning and education are inherently social: Research on how people learn suggests that learning and cognition are complex social phenomena distributed across mind, activity, space, and time (Dunleavy, Dede & Mitchell, 2009).

It will be suggested that social interaction can provide a "new" form of immersion that is slightly different from the forms that have been distinguished (*actional immersion* as being immersed in a task, *narrative immersion* which is achieved by (fictional) narratives that lead to powerful semantic associations and *sensory immersion* which can be experienced when using immersive displays, Dede, 2009). *Immersion* via *social interaction* will be experienced when teacher and learner or learners amongst themselves engage in exchange or collaboration on the learning contents. Against the background of these considerations, this chapter will focus on those aspects of using virtual reality technology which either foster social interaction among humans or inherently entail social interaction because one of the entities included in the setting is artificially built to provide a social learning situation.

When focusing on social aspects of instructional communication in immersive media, it is important to provide theoretical models that can help systematize research in this area. Several researchers have suggested appropriate theoretical frameworks (Kim & Baylor, 2006; Veletsianos & Russell, 2014). First and foremost, Bandura's (2001) social cognitive theory has been named as suitable background: Within all kinds of immersive media, other students or autonomous teacher agents can be seen as fostering learning by serving as a model for specific behavior—especially when the other shares some similarities with the learner. Also, Kim and Baylor (2006) refer to distributed cognition (Salomon, 2001): based on the assumption that cognition is distributed among individuals, tools, and artifacts, an interaction with other learners in an immersive environment or an autonomous agent's communicative abilities can be used as scaffolding mechanisms by asking questions or giving hints (Veletsianos & Russell, 2014). When enhanced by adding a social dimension, also cognitive theory of multimedia learning might be seen as a suitable framework (Mayer & DaPra, 2012). Also, Vygotsky's zone of proximal development (Vygotsky, 1978) is often referred to as he already claimed that adding a social dimension to the learning situation is important. The understanding that learning is a social situation helps to clarify that not only the cognitive impact has to be appropriate but also the social interaction has to work in order to make instructional communication beneficial: Here, the establishment of common ground (Clark, 1996), for example between instructor and student, but also between collaborating students, can be mentioned as decisive and can be seen as a prerequisite for instructional communication. Here, the student must be able to understand the instruction correctly and—probably more importantly—the teacher has to be able to recognize whether shared meaning or common ground have been achieved. Also, peers learning together need to be supported by technology in a way that they can be sure that their hints, explanations or questions were understood by the fellow student trying to benefit from the explanation or trying to clarify a problem or its solution. Klopfer's chapter provides examples of this. The need to analyze and solve these issues by developing appropriate media environments has long been recognized in the field of computer-supported-collaborative-learning (CSCL, and similarly in Computer-Supported-Cooperative-Work, CSCW, and human-computer-interaction, HCI, research). Here, a rich body of research laid the groundwork for understanding and supporting learning related social interaction in mediated environments. One important notion suggested by this research realm is the insight that mediated communication is not necessarily deficit-laden but that technologies always also entail specific benefits which might ease, support or enhance communication. Gardner and Scheaffer's chapter provides examples of this.

In the following, three lines of research which are each connected to specific technology, will be presented. First, building on CSCL, transformed social interaction, a specific form of immersive virtual reality applications will be discussed that enrich communication by unique opportunities provided by immersive systems. Here, the fabrics of social interaction are manipulated while people are interacting within immersive virtual worlds, for example, by altering smiling or gaze behavior. Then, the state of the art with regard to pedagogical agents will be presented and discussed with a special focus on social instead of cognitive aspects and effects. Finally, augmented reality is targeted which does not only allow for situated learning but is also well suited to enable social interaction that is fueled by narratives connected to the displayed virtual entities.

4.2 Technologies Fostering Social Immersion

4.2.1 Transformed Social Interaction

The notion that new technology bears unique opportunities for human-human social interaction in learning realms is especially true for "Transformed Social Interaction" (Bailenson, 2006). Here, social interaction is conducted within an immersive virtual reality and is amended in ways that would not be possible when interacting face-to-face. Immersive virtual reality is realized by all interactants wearing motion capture devices such as optical, magnetic, or mechanical sensors or (more recently) facing video analyzing technology (such as included in the WII) that track aspects of their behavior (e.g., walking, head movement, gestures, gaze, facial expressions). The tracked behavior is then broadcasted to the other interactants by means of virtual reality, for example, an avatar, that is a virtual person that is animated based on the tracked person's movements (and vice versa). However, unlike in direct face-to-face situations the behavior does not have to be transferred naturalistically, i.e., in the exact way it is shown but can be altered by algorithms (Blascovich & Bailenson, 2012). By means of immersive displays every user is placed in an immersive virtual world in which the environment and other users' behavior are rendered and displayed stereoscopically by means of a device such as an HMD or Oculus Rift. Thereby, individuals from different (potentially remote) places can join the same virtual world. As mentioned above, their interaction behavior can either be transferred naturalistically, i.e. in the way it is produced by the individuals, or can be altered by algorithms. This is possible because collaborative virtual environments render the world separately for each user simultaneously, so that the interaction appears differently for each user and potentially different from what happened in the real world (Bailenson, 2006). Here, three dimensions are distinguished which are meant to classify each currently conceivable alteration of reality: situational context/social environment, sensory abilities, and self-representation. With regard to *situational context/social environment* people and things can be represented at different locations and different time-settings. Therefore, the spatial or temporal structure of a conversation is transformed. In a learning environment this entails, for instance, that every learner can sit right in front of the virtual blackboard (while the other students—who perceive themselves to be in front—are perceived as sitting behind the learner). The ability to alter time can enable a student to "pause" or "rewind" during a conversation (which might increase comprehension). While the alteration of time does not necessarily increase immersion in the situation, the possibility to place learners in different environments and in different locations within a specific environment can foster immersion.

Sensory abilities describes the possibility to augment the sensoric potential by adding information that humans usually cannot perceive or derive consciously. Dede's chapter provides illustrations of this. Here, the system would provide aggregated information about other participants (e.g., how often did he/she gaze at the blackboard; how often did he/she smile or frown?). Bailenson (2006) suggests to realize this by providing "invisible" consultants. This algorithm-based, real-time summary information about the attentions and movements of other interactants is automatically collected by the virtual environment technologies. Teachers in a distant learning scenario can thereby either control whether learner seem to be attentive or can control their own behavior, when, e.g., receiving information about whether they spread their attention evenly. Apart from altering social interaction, there are many other forms of transforming sensory abilities, for example, shrinking to the microscopic level to observe things invisible at the macroscopic level, or seeing wavelengths of light invisible to human eyesight (e.g., infrared) (Dede, 2009).

The probably most important and most analyzed opportunity, however, is *self representation*, meaning the potential that appearance and/or behavior of the user is manipulated. Slater's chapter discusses several examples of this. The virtual representation of a person can be taller, shorter, more attractive, than in reality or can be altered with regard to sex, age, or race. Also, the nonverbal behavior can be altered and, for example, more or less smiling can be shown. With regard to the latter, recent results show that a conversation indeed is perceived as more positive and that interactants feel more positive affect when the smiling behavior is enhanced (Oh, Bailenson, Krämer, & Li, see Fig. 4.1). This effect could also be capitalized on in learning situations by either in general having the teacher display more smiling or having the teacher show enhanced smiling only to those students who react favorably to this and show a stern face to others who might be more impressed by this (Bailenson, 2006). The impact of gaze has been shown impressively in studies of the so-called non zero sum gaze paradigm. While in face-to-face interactions, a person can either look at one conversation partner OR the other, in a virtual environment it is possible to look at both at the same time (since the virtual environment and all avatars are individually rendered for each individual user and therefore one person can be rendered differently for each other interactant). Empirical studies have indeed demonstrated that it lead to positive effects when gaze was augmented and a person looked at two others for 100% of the time each (Beall, Bailenson, Loomis, Blascovich & Rex, 2003). People being gazed at 100% of time returned gaze more often and were more persuaded by the person with augmented gaze (see Fig. 4.2).

With regard to the manipulation of one's avatar's appearance two strands of research can be distinguished: In *identity capture* studies (Bailenson, Garland, Iyengar, & Yee, 2004) it was demonstrated that virtual interaction partners that by

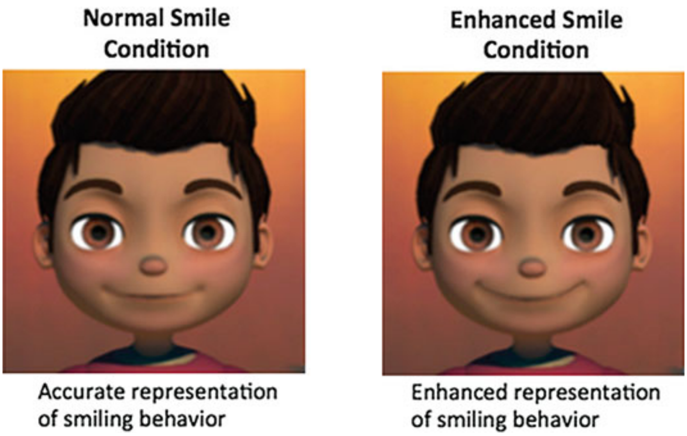

Fig. 4.1 Avatar with normal smile and enhanced smile (Oh et al., 2016a)

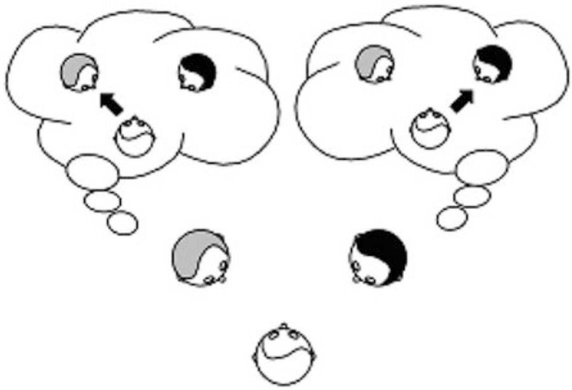

Fig. 4.2 Non zero sum gaze (Beall et al., 2003)

morphing techniques include aspects of the specific subjects' facial structure were perceived as more favorable. While this can easily be explained by findings that people show affinity towards something that bears resemblance to themselves it suggests intriguing possibilities for rendering student-teacher interactions smoother (learner and teacher perceiving each other to be similar to themselves). Second, the proteus effect (Yee & Bailenson, 2007) describes the possibility to alter the participant's appearance in a way that he/she perceive themselves (by the help of a virtual mirror) as member of a different gender, age or race and by this literally step into the shoes of another person. Numerous studies have shown that people alter their attitudes and/or their behavior in accordance with the appearance they assume. For example, people who embodied an elderly person reduce ageism more compared to those who engaged in mere perspective taking (Oh, Bailenson, Weisz, & Zaki, 2016b; see also the chapter by Mel Slater in this book).

To conclude, with regard to the social aspects of learning, all of these different forms of transformed social interaction are particularly interesting as they enable researchers to take apart the fabric of social interaction. By this, scholars can (a) use TSI in order to analyze and understand the mechanisms of social interaction and (b) can utilize the technological possibilities directly to improve learning situations when they are conducted within immersive virtual environments.

4.2.2 Animated Pedagogical Agents

Besides transformed social interaction which targets human-human-interaction in immersive environments, other technology tries to incorporate autonomously acting entities in immersive settings that are based on artificial intelligence. These so-called pedagogical agents autonomously interact with and support the learner as tutor or peer. Even if so far no respective applications exist, these agents are conceivable to enhance social learning in Virtual Reality and Augmented Reality environments (for example in EcoMOBILE, http://ecomobile.gse.harvard.edu).

Pedagogical agents have long been suggested as emerging technology in order to enhance students' learning and motivation. Future systems are expected to enhance e-learning programs for individual learning with a human-like motivator or to support teachers in the classroom by attending to small groups of students. As one major advantage of these embodied automatic tutors, their advocates claim that pedagogical agents can, or will be able in the future, communicate via verbal and nonverbal means, thus facilitating and personalizing the interaction with an e-learning program (see Fig. 4.3). Furthermore, increased motivation is expected: Baylor and Ryu (2003) suggest that the key advantage is that human-likeness creates more positive learning experiences and provides a strong motivating effect. In line with these assumptions, research on pedagogical agents suggests that even the mere social presence of an embodied autonomous tutor might be capable of fostering interest, attention, and subsequently learning.

Several overviews of pedagogical agent research (Baylor, 2001; Heidig & Clarebout, 2011; Moreno, 2004) outline various developments, theoretical assumptions on effects and results of evaluation studies. With regard to developments, systems from both cognitive and educational psychology and from the field of computer science have been presented. For example, based on discourse analyses of face-to-face tutoring lessons, Graesser, Wiemer-Hastings, Wiemer-Hastings, Kreuz, and The Tutoring Research Group (1999) constructed the AutoTutor as a dialog partner, which by asking questions and giving feedback helps the student to actively construct subjective explanations and engage in deep reasoning. Here, the agent utilizes a hint–prompt–elaboration circle until the learner utters the correct answer. A talking head is used in order to ground the conversation between the tutor and the learner by means of nonverbal feedback cues (nodding or shaking the head, facial expressions). Similarly, also Baylor and colleagues provide a sophisticated learning program that is amended by simple embodiment techniques and basic nonverbal capabilities (Baylor & Ryu, 2003). Here, the focus is clearly on social interaction and social support for the learner (Kim & Baylor, 2016). One of

Fig. 4.3 Virtual agent

the oldest, but nevertheless ground-breaking systems has been presented by Rickel and Johnson (2000) who locate their agents in a virtual learning environment. Agent Steve leads learners through a US navy ship and is capable of reacting to changes in the virtual environment as well as to learners' behavior. Based on information on the environment and the learner, he asks the student appropriate questions or gives explanations. The best known pedagogical agents are probably the systems by Lester et al. (2000) who developed various agents that are supposed to motivate children to learn within desktop-based learning environments. Some of these agents are able to use gestures and movements to highlight objects, but are also capable of displaying a wide array of emotions.

4.2.2.1 Results on the Effects of Pedagogical Agents

Several reviews and meta-analyses on pedagogical agents report that there is empirical support for the notion that pedagogical agents motivate the learner and lead to increased learning (Baylor 2001; Moreno 2004; Schroeder, Adesope, & Gilbert, 2013). However, results are not consistent and mostly show small effect sizes. For example, Graesser, Jackson, and McDaniel (2007) concluded that AutoTutor improves learning by nearly one letter grade compared with reading a textbook for an equivalent amount of time or in comparison with a pretest. However, Rajan et al. (2001) demonstrated that it is first and foremost the voice that is responsible for these effects. Baylor and colleagues provided more evidence for an impact of pedagogical agents on learners' subjective experiences, but not on their performance and learning outcome (Baylor & Ryu, 2003). Moreno (2003) further summarized that—in line with results that especially the voice is decisive—there is no evidence for the social cue hypothesis as it has not been shown that the mere presence of social aspects such as a human-like body leads to distinct effects. However, the cognitive guiding functions provided by vocalizations and a program's didactic concept did prove to be influential. Moreno concluded that the main strength of pedagogical agents resides in the specific instructional method embedded in the agent rather than in the visual presence of the agent itself. Also, recent research (Carlotto & Jaques, 2016) as well as a recent meta-analysis (Schroeder & Adesope, 2014) has supported the notion that voice is more important than nonverbal expressiveness.

However, these results have to be considered with caution given the fact that the systems that had been evaluated did not (yet) include very sophisticated nonverbal behavior. Nonverbal behavior as it is used in face-to-face interaction includes facial displays and all kinds of kinesics in the sense of body movement. It needs to be acknowledged that nonverbal behavior is very complex: The dynamics of the movements are important, very subtle movements have distinct effects (e.g., head movements such as a head tilt) and the effects are context-dependent (e.g., a smile leads to a different effect when accompanied by a head tilt). This complexity, however, is mostly not considered and implemented in pedagogical agents. For example, as Graesser himself acknowledges, the nonverbal implementations as well as their theoretical foundations for AutoTutor are rather shallow and fall short of the sophisticated dialogue model, while Rickel and Johnson (2000) focused more on multimodal input (e.g., tracking the student's behavior) than multimodal output (e.g., deictic gestures and further nonverbal behaviors). Also, Lester's agents do not show gestures and movements which represent human nonverbal behavior—especially as the agent is only partly anthropomorphic. So far, only very few pedagogical agent systems (even more recent ones) have achieved realistic and sufficiently subtle nonverbal behavior in order to administer a fair test. And indeed, when employing technology that provides realistic, dynamic nonverbal behavior, results show that nonverbal rapport behavior leads to an increase in effort and performance (Krämer et al., 2016). Therefore, the conclusion that embodiment and nonverbal behavior is less decisive compared to voice is premature. On the other hand, there are studies which have demonstrated considerable effects of nonverbal behavior even though the cues displayed were very basic (eye gaze of a comic-style agent, realized by eye-direction of the eyeball only, Lee, Kanakogi & Hiraki, 2015). Similarly, Mayer and DaPra (2012) present evidence for the "embodiment effect" in the sense of the question whether nonverbal behavior will yield better learning results. They demonstrate both increased values regarding a learning transfer test and more positive ratings of the social attributes of the agent. They explain the result with social agency theory (Mayer, 2005): social cues from a social agent prime a social stance in learners that causes them to work harder by activating deep cognitive processing in order to make sense of the presented material.

4.2.2.2 The Importance of Social Processes When Building Pedagogical Agents

Recent developments increasingly take the fact that learning is a social process into account. While there are still studies focusing on cognitive and metacognitive aspects, more and more priority is set on the social relationship with the user. Instead of merely providing expert guidance, the agents are considered as tools to support learners by social and affective capabilities (Kim & Baylor, 2016; Krämer & Bente, 2010; Veletsianos & Russell, 2014). Kim and Baylor (2006) argue that learning environments should provide situated social interaction since it is well documented that the cognitive functioning of learners is framed by social contexts and that teaching and learning are highly social activities.

Situated social interaction, as Kim and Baylor argue, can be realized by pedagogical agents that simulate human instructional roles such as teacher or peer. Similarly, Graesser (2006) states that social psychological aspects have to be considered in pedagogical agent research since cognitive representations might be social. He specifies conditions under which more or less social context has to be provided and concludes that the social context of knowledge construction is particularly important when knowledge is vague, open-ended, underspecified, and fragmentary. As a consequence, especially when building computer systems that can conduct effective conversation, the system has to possess basic social abilities in terms of having internal representations of the knowledge, beliefs, goals, intentions, and values of the human user (see Krämer 2008, who argues in favor of implementing a theory of mind).

Some systems already explicitly consider social aspects: For example, in several developments agents take the role of a (fellow) student instead that of a teacher and foster learning by the fact that the student has to engage in explaining the learning matter to the (artificial) peer (see, for example, the teachable agents paradigm, Schwartz, Blair, Biswas, & Leelawong 2007). According to Veletsianos and Russell (2014) these agents are expected to lower learner anxiety (by seeming less threatening than instructors), act as role models and "teach" via giving the students the chance to detect mistakes that the agent makes during the learning process. Another possibility to engage the learner socially has been presented as social instructional dialog (Ogan, Aleven, Jones, & Kim, 2011) by which the agent tries to improve learner-agent interpersonal relations. Agents who used conversational strategies assumed to produce positive interpersonal effects, lead to positive effects on learners' entitativity (feeling of working together in a team), shared perspective, and trust with the agent.

Therefore, with a view to social psychological aspects the distinction between different roles of the agent as either a mentor, a peer or a protégé is important. Against the background that by means of pedagogical agents developers attempt to replicate useful human characteristics in the virtual world, future research needs to gain insights on what the desirable and beneficial attributes for each role in face-to-face interaction are. These attributes can be transferred to the virtual agents in order to test whether these attributes also have beneficial effects in VR.

At least with regard to the agent's role as mentor, future research can build on Klauer's (1985) taxonomy of teaching functions that have been proposed by Heidig and Clarebout (2011) as useful for the realm of pedagogical agents: motivation, information, information processing, storing and retrieving, transfer of information, monitoring and directing.

What is additionally important to note, is that social effects of agents are to be expected anyway: early evaluation studies of conventional computers characterized by human-like attributes (Reeves & Nass, 1996) as well as with embodied conversational agents provided evidence that machines and agents are readily perceived as social entities: even minimal cues and similarity with humans suffice to lead users to show behavior that would be expected in human–human interaction. It is therefore plausible to assume that learners will also interact socially with pedagogical agents. This will also enhance chances that social mechanisms of learning will also transfer to the virtual world.

Given the open questions, e.g. with regard to the effects of the agents' nonverbal behavior, future research is needed. This is best conducted against the background of a coherent theoretical framework that is able to explain the mechanisms. There have been suggestions for frameworks for future studies (Heidig & Clarebout, 2011) as well as suggestions on the necessities for methodology. With regard to the latter, it will be important to test agents in naturalistic settings and in longterm studies (Veletsianos & Russell, 2014; Krämer & Bente, 2010).

4.2.3 Augmented Reality for Learning Interaction

Augmented realities also have enormous potential for learning environments and can—depending on how they are shaped—also especially foster beneficial social interaction. Recently, several researchers proposed to employ augmented reality technology in learning settings.

Augmented reality is characterized as enhancement of the real world by computer-generated content which is tied to specific locations or activities (see e.g., Yuen et al., 2011). The digital content is laid over the vision of the real world. By means of tablets or smartphones (and therefore available to a large percentage of people), text, audio, images, 3D models or video can be mixed into the users' perceptions of the real world. A large number of Augmented Reality applications rely on GPS technology implemented in the devices and offer location-based services. The specific location can be enriched with relevant narrative, navigation, and/or academic information. Bower et al. (2014) conclude that by this kind of location-based procedure, information for students can be provided at the exact time and place of need. By this, cognitive overload can be reduced as students experience "perfectly situated scaffolding". Schneider's chapter provides examples of this.

Yuen et al. (2011) enthuse over the emerging possibilities for education and suggest that the dream of ubiquitous learning now becomes reality and will enable learners to access a wide range of location-specific information. By this, the users' perceptions and knowledge is enhanced.

Although the technology is still young, already several overviews on research in educational context have been presented (Dunleavy & Dede, 2014). Wu, Lee, Chang, and Liang (2013) in a literature review for the years 2000–2012 find 54 papers on AR in education. Yuen et al. (2011) and Wu et al. (2013) summarize the benefits that Augmented Reality can have for teaching and learning environments: Among other aspects such as fostering student motivation, creativity and imagination or experiencing phenomena not observable in the real world, the enhancement of collaboration between students and instructors as well as among students is named. Wu et al. (2013) classify instructional approaches with augmented reality in three major categories: engaging learners into *roles*, focusing on interactions with *locations* and emphasizing *tasks*. With a view to social immersion especially the category *role* is important. Here, participatory simulations, role playing and jigsaw approach can be distinguished. All of these foster interaction and collaboration among students, but all employ different mechanisms for engaging users in a joint learning task: For example, in participatory simulations students jointly simulate a phenomenon (e.g. the spreading of a virus) by means of beaming information from handheld device to handheld device (Klopfer, Yoon, & Rivas, 2004). Roleplay can be helpful in comprehending complex mechanisms such as, for example, the socially situated nature of scientific investigations by means of socially immersing students by assigning roles of scientists, environmental investigators and activists (Squire & Klopfer, 2007). The name jigsaw approach stems from the fact that different students receive different parts of the "puzzle" in the sense that this approach fosters collaboration by assigning different roles and different knowledge to students who need to solve a problem together (Dunleavy et al., 2009; see Wu et al., 2013).

Overall, especially game-based learning can be helpful in engaging students socially and immersively. Yuen et al. (2011) report that in 2000 Bruce Thomas created the first outdoor AR game "AR Quake" (Thomas, Close, Donoghue, Squires, Bondi, & Piekarski, 2001) with many more to follow (von der Pütten et al., 2012).

A game that combines augmented reality, social interaction and education is the AR game Alien Contact (Dunleavy et al., 2009). Students play different roles in a team and have to form hypotheses by collecting evidence and complete tasks from maths, science, and language skills. Qualitative evaluations with middle school and high school students demonstrate that the game is perceived as highly engaging. The authors attribute this engagement to the innovative tools whose attractiveness for learning, however, will decline over time. Therefore, they recommend to identify curricular-specific and technology-specific characteristics which might be combined with sound pedagogy in order to keep students engaged over time (Dunleavy et al., 2009).

For the future, further developments such as augmented reality holographic projection can be expected (Yuen et al., 2011). Thereby, video conference-like meetings and an effortless communication over a distance can be realized. This might improve early attempts to bring together people and their virtual representations. For example, education-related events in Second live virtual worlds could be replaced by holographic projection. This could be useful especially in different forms of online courses and distance learning such as Massive Open Online Courses, in which collaborative endeavours in small groups can be supported by holographic representations. As Huang, Rauch, and Liaw (2010) describe, VR technologies that support immersive learning are expected to bear great potential for social scaffolding in collaborative learning.

4.3 Conclusion

Since learning situations and instructional communication are inseparably interwoven with social interaction (Dunleavy et al., 2009; Rummel & Krämer, 2010) it is important to also cater for social needs when employing immersive technologies in learning settings. With regard to pedagogical agents this will entail that researchers have to contribute to building the necessary capacities, by, for example, developing nonverbal behavior that is suited to foster learning. As a means to this end, transformed social interaction research will also be helpful in identifying which social signals are most beneficial with regard to supporting learning. Since TSI allows to manipulate teachers' and learners' behavior in a virtual environment it is not only helpful in order to actually implement suitable behavior (for example to render a teacher who does not smile friendlier towards students who need this), but also in order to serve as a research tool helping to understand the fabrics of social interaction. With regard to augmented reality it will be important to not only consider cognitive aspects of learning but to also take social aspects into account by, for example, developing narrative structures that will invite social interactions between learners or between learners and teachers as this will not only deepen the experience but also the learning outcomes.

For all forms of immersive social learning experiences it will further be important to derive future developments from theoretical frameworks that have to be refined for these contexts. Only then it can be achieved that the natural relation between learning and social interaction is further optimized by means of technology that increases social immersion with a view to better learning outcomes.

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Chapter 5
Assessment for Learning in Immersive Environments

Valerie Shute, Seyedahmad Rahimi and Benjamin Emihovich

Abstract Immersive Environments (IEs) hold many promises for learning. They represent an active approach to learning and are intended to facilitate better, deeper learning of competencies relevant for success in today's complex, interconnected world. To harness the power of these environments for educational purposes (i.e., to support learning), we need valid assessments of the targeted competencies. In this chapter we focus on how to design and develop such valid assessments, particularly those providing an ongoing, unobtrusive collection and analysis of data as students interact within IEs. The accumulated evidence on learning thus provides increasingly reliable and valid inferences about what students know and can do across multiple contexts. This type of assessment is called "stealth assessment" and is applied toward the real-time measurement and support of learning in IEs—of cognitive and non-cognitive variables. The steps toward building a stealth assessment in an IE are presented through a worked example in this chapter, and we conclude with a discussion about future stealth assessment research, to move this work into classrooms for adaptivity and personalization.

Keywords Augmented reality · Diagnostic assessment · Immersive environments Stealth assessment · Digital games · Virtual reality

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5.1 Introduction

In this chapter, we examine immersive learning environments (e.g., virtual reality, augmented reality, and digital games) and techniques toward the measurement and support of knowledge and skills therein. Our premise is that immersive environments (IEs) represent an active approach to learning and should thus facilitate better, deeper learning of competencies relevant for success in today's increasingly complex world. Such environments also permit the application and practice of competencies in relatively safe and authentic spaces. Moreover, well-designed IEs that incorporate theoretically-grounded learning principles (authentic problem solving, rules/constraints, challenge, control, ongoing feedback, and sensory stimulation—see Shute, Ventura, Kim, & Wang, 2014) can be intrinsically motivating and therefore engaging; and student engagement is a key component of learning (Dede, 2009).

The IEs on which we focus are based on learning through experiencing, and understood through the theoretical lenses of constructivism (Piaget, 1973) and situated learning (Lave & Wenger, 1991). These theories emphasize active learners who construct meaning (Vygotsky, 1978). Constructivism states that effective learning environments are interactive places where learners achieve learning goals by collaborating with tools, information resources, and with others. Situated learning views cognition as being nestled within the activity, context, and culture in which it is developed. The learner is active in the learning process, where "doing" is more important than listening, and the learner determines the pace of learning.

Constructivism and situated learning are not, however, solely cognitive in nature as affect and cognition are complementary processes within all forms of learning. For example, cognitive complexity theory predicts that well-designed IEs facilitate learning by simultaneously engaging students' affective and cognitive processes (Tennyson & Jorczak, 2008). Affective processes are dependent on how environmental stimuli engage the student.

Similarly, flow theory (Csikszentmihalyi, 1990) argues that flow—a positive experience associated with immersive environments—is an optimal learning state induced by intrinsic motivation, well-defined goals, appropriate levels of challenge, and clear and consistent feedback. Attaining a state of flow involves motivation, effort, and sustained attention thus there is a convergence between the core elements of well-designed IEs and the characteristics of productive learning (Shute et al., 2014).

The purpose of this chapter is to describe how to design and develop valid assessments to support learning in immersive environments, particularly in well-designed digital games. The basic idea is that learners' interactions within such environments generate large amounts of data—cognitive and non-cognitive—which may be captured in log files and analyzed to yield cumulative estimates of current states of targeted competencies (Shute, Leighton, Wang, & Chu, 2016a). The results of the ongoing analyses can be used as the basis for feedback and other types of learning support, such as adapting the environment to fit learners' needs.

In the following sections of this chapter, we review the relevant literature on IEs and their effects on learning, examine the role of diagnostic assessment in immersive learning environments by introducing stealth assessment, provide an example of stealth assessment within a well-designed game, and discuss next steps in this research. Our overarching thesis is that: (a) learning is at its best when it is active, goal-oriented, contextualized, and motivating; and (b) learning environments should thus be interactive, provide ongoing feedback, capture and hold attention, and have appropriate and adaptive levels of challenge. Advances in technology, the learning sciences, and measurement techniques help to support these features through the design of IEs with deeply embedded assessment of targeted competencies.

5.2 How Does Immersion Improve Learning?

In this chapter, immersion refers to the subjective impression one experiences when interacting with a realistic, digitally-enhanced environment (Dede, 2009). Immersion may be experienced within contexts such as: (1) Virtual Reality (VR), where learners wear VR gear and go into an immersive computer-generated world with the illusion of "being there" or having a sense of presence, with immediate adjustments of the environment according to the learner's head or body movements; (2) Multi-User Virtual Environment (MUVE), where learners can enter a 3D virtual world with their digital avatars and virtually interact with other people (Hew & Cheung, 2010); and (3) Mixed Reality (MR) or Augmented Reality (AR), that combines digital information (e.g., images, videos, 3D objects, and audio layers) with real-world settings, and allows users to interact in real-time within a rich immersive experience (Barfield, 2015). Well-designed digital games can provide immersive experiences in any of these three types of environment.

Interactions within an immersive environment produce a suspension of disbelief for learners (i.e., sacrificing realism and logic for the sake of enjoyment) that can be further enhanced when the immersive environment incorporates design strategies that emphasize actional, symbolic, and sensory elements (Dede, 2009). One clear benefit of immersive environments is that they allow participants to safely engage in actions that might be considered too risky or difficult in natural environments (actional immersion). For example, training medical students on triage processes is difficult due to the constraints in which activities undertaken during training reflect the natural world conditions where triage is needed, such as a natural disaster or a plane crash. Replicating the realism and extent of injuries along with patient deterioration using natural world training is both expensive and incompatible for an individual learning experience. Given the natural world restrictions of triage training, researchers designed, built, and tested an immersive game to support learning about how to conduct a triage sieve, as taught in a Major Incident Medical Management and Support Course (MIMMS) in the United Kingdom.

The game, *Triage Trainer* (Knight et al., 2010), was evaluated relative to its effectiveness, compared to traditional learning methods (i.e., card sorting exercises). A total of 91 participants (i.e., 44 in the card-sorting group and 47 in the *Triage Trainer* group) were tested on their ability to correctly prioritize each casualty (tagging accuracy) as well as follow the procedure correctly (step accuracy). According to Knight et al. (2010), participants using *Triage Trainer* performed significantly better than the card-sorting group for tagging accuracy ($\chi^2(5) = 13.14$, $p < 0.05$) (i.e., 72% compared to 55%, respectively). In addition, the step accuracy results indicated four times as many participants in the *Triage Trainer* group (28%) correctly triaged all eight of the casualties compared to the card-sorting group (7%), and significantly more participants in the *Triage Trainer* group scored the maximum compared to the card-sorting group ($\chi^2(1) = 5.45$, $p < 0.05$).

In addition to cognitive effects, well-designed digital games that fully immerse learners in environments often elicit affective reactions (e.g., excitement, boredom, confusion, frustration) that differentially influence learning, such as the development of problem-solving skills and spatial abilities (e.g., Shute, Ventura, & Ke, 2015). Furthermore, there are several conditions of gameplay that one can experience in well-designed digital games (e.g., identity formation, persistent problem solving, practice, and interaction) that impact motivation, which in turn promotes engagement and meaningful learning (Clark, Tanner-Smith, & Killingsworth, 2014).

Consider the game *World of Warcraft* (WoW). This is a good example of a fully immersive digital game in which the learning takes place in a goal-driven problem space where players negotiate different contexts (i.e., levels, scenarios, interactions) solving assorted problems with their avatars (Gee, 2008). Playing WoW successfully requires various competencies (e.g., problem-solving skills and collaboration) as well as planning and executing strategies synchronously to accomplish goals. As players traverse each level in WoW, it is natural to reflect on and process gameplay choices, which helps to promote a more motivating gameplay/learning experience. Players additionally enjoy customizing different skills and abilities for their avatars because different combinations of abilities can lead to improved gameplay performance, which results in greater rewards earned.

An example customization by game players includes design modifications to the game that build models to be used for: (1) in-game performance improvement, and (2) addressing a naturally occurring and frustrating in-game problem—i.e., dealing with freeloaders. Thus, to improve in-game avatar performance, WoW players created an add-on modification called *Skada Damage Meter,* which displays how well each person in a group is performing based on feedback that is given to players as a percentage of damage or healing done per avatar. *Skada Damage Meter* displays a chart with various metrics such as overall damage done, damage per minute, overall healing done, and healing per minute. These metrics enable group leaders to identify which players are underperforming based on their avatar role (i.e., damage absorber, damage dealer, and healer). Developing this modification illustrates how players were sufficiently motivated to solve a WoW problem, which has a real-world parallel in workplace environments (i.e., individuals who attempt benefit from the success of others by trying to obscure their incompetent skills).

In addition to promoting problem-solving skills through gameplay, immersive games can serve as learning vehicles to support the development of knowledge and skills across various domains including: inquiry-based science learning with Quest Atlantis (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005) and River City (Ketelhut, 2007), spatial skills with Portal 2 (Shute et al., 2015), and computational problem-solving (Liu, Cheng, & Huang, 2011) with TrainB&P (Train: Build and Program it). Immersion fosters learning by enabling multiple frames of reference and situated learning experiences (Dede, 2009). These multiple frames of reference provide different benefits for immersive learning. For instance, egocentric frames of reference support immersion and motivation through embodied learning, while exocentric frames of reference support abstract symbolic insights when one is further from the context of the environment.

Immersive environments also enhance a contextualized understanding of instructional content for learners in ways that are often decontextualized in formal learning settings. As mentioned earlier, these environments support meaningful learning experiences that are grounded by situated learning and constructivism learning theories. Situated learning is an active process that can generate excitement and curiosity in the learner to acquire knowledge by constructing meaning through specific problem-solving scenarios (Barab et al., 2005). Situated learning can also involve the adoption of multiple roles and perspectives and receiving guidance from expert modeling (Bransford, Brown, & Cocking, 2000). Through immersive interactions and gameplay, novice players can develop their skills by observing, communicating and interacting with other expert players; essentially emulating how junior scholars learn from their advisors in academic environments. In addition, players acquire in-game terminology through interactivity and communication with experts and novices, and language acquisition is an essential element to scaffolding.

Finally, immersive gameplay or other in situ interactions enable learners to traverse the zone of proximal development (ZPD; Vygotsky, 1978), which refers to the distance between what a learner can do with support by collaborating with peers or through guided instruction, and what they can do without support. The acquisition of knowledge begins with interaction, followed by the acquisition of language which provides meaning and intent so that behaviors can be better understood. Towards that end, well-designed IEs consist of rules, goals, feedback, skill mastery, and interactivity. To achieve quantifiable outcomes, players must acquire knowledge, skills, and other abilities. Immersive environments like digital games also promote play which is integral for human development, and is vital to assimilating and accommodating new information by interacting with a fluid environment (Shute et al., 2015). Well-designed IEs promote learning by requiring learners to apply various competencies (i.e., creativity, rule application, persistence) to solve novel problems thereby providing meaningful assessment environments for learners during gameplay. So how can these evolving competencies be accurately measured and thereby used as the basis for good evidence-based learning support?

5.3 Assessment in Immersive Environments

Assessment of student learning in IEs should not be measured using traditional summative tests (Shute, Leighton et al., 2016a). Such standardized tests provide a very narrow snapshot of student learning. Moreover, traditional assessments cannot provide immediate feedback to support learning or adapt the environment to learners' needs. Therefore, it is not surprising that the question of how to administer responsive, comprehensive, and balanced assessments within IEs is an emergent and complex question. Immersive environments provide novel learning opportunities that demand new assessment methodologies.

Shute (2011) used the term "stealth assessment" to refer to evidence-based, ongoing, and unobtrusive assessments, embedded within IEs (e.g., digital games, virtual reality, augmented reality). Stealth assessments capture, measure, and support the development of learners' targeted competencies in IEs which serve as vehicles for learning. Stealth assessment can be used to adapt the environment to accommodate learners' current levels/needs, as well as to provide appropriate feedback and other types of learning support (Shute, Ke, & Wang, 2017). According to Csikszentmihalyi (1990), such personalized support permits learners to maintain the state of flow (note: adaptivity is further discussed in the next section).

As a learner interacts with the IE (e.g., an augmented reality activity or video game), stealth assessment analyzes specific actions and interactions via data that are captured in the log file to estimate the learner's competency states in terms of evidence-based claims. Stealth assessment creates a student model and continuously updates it as the person interacts with the IE. Information from the student model, then, can be used as the basis for which to provide relevant feedback and/or adapt the IE to suit the learner's needs. In the process, this creates a personalized learning/playing experience.

Stealth assessment employs a principled assessment design framework called evidence-centered design (ECD; Mislevy, Steinberg, & Almond, 2003). ECD involves the development of conceptual and computational models (e.g., the competency, evidence, and task models) that work together to accomplish valid assessment (see Fig. 5.1).

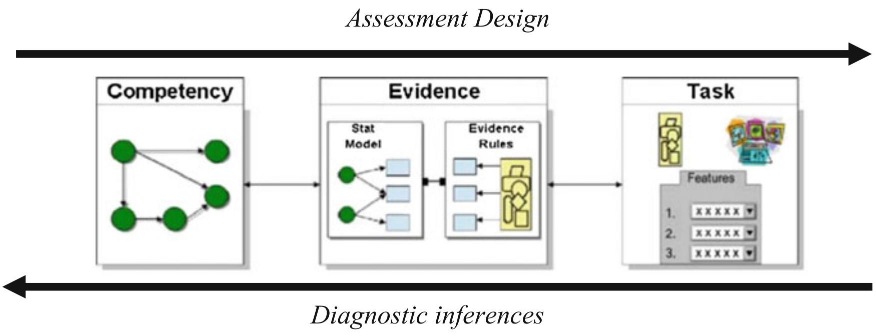

Fig. 5.1 Simplified ECD adapted from Mislevy et al. (2003)

The first model in ECD framework is the competency model, which explicitly specifies the knowledge, skills, and other attributes (collectively referred to as "competencies" in this chapter) to be measured by the assessment. This is intended to facilitate the operationalization of the construct with all of its associated facets and observable behaviors. The second model is the evidence model, which specifies the assignment of scores to the observable behaviors (i.e., the learner's performance), such as whether dichotomous (i.e., an item response or activity is assigned a value of 1 if correct, otherwise a 0) or polytomous (i.e., an item response or activity is assigned values other than just 0 or 1 to show increasing performance quality) scoring will be used, and how the scores will be accumulated. Finally, the third model is the task model, which outlines the types of tasks, including all features, requiring development to elicit the competencies of interest from the learner.

Stealth assessment's evidence-based models work together to accomplish ongoing analyses of all gameplay/interaction data. This provides more valid and reliable assessment results compared to traditional summative tests. Shute et al. (2017) delineate the steps for creating a stealth assessment in an IE:

1. Develop the competency model (CM) of targeted knowledge, skills, or other attributes based on comprehensive literature and expert reviews
2. Determine the IE (e.g., a game or other immersive media applications) into which the stealth assessment will be embedded
3. Create a full list of relevant actions/indicators that serve as evidence to inform the CM and its facets
4. Create new tasks in the IE, if necessary
5. Create a matrix to link actions/indicators to relevant facets of target competencies
6. Determine how to score indicators by classifying them into discrete categories for the "scoring rules" part of the evidence model (EM)
7. Establish statistical relationships between each indicator and associated levels of CM variables using, for example, Bayesian Networks (BNs) (EM)
8. Pilot test the BNs and modify parameters
9. Validate the stealth assessment with external measures
10. Use the assessment estimates to provide feedback and targeted learning supports in the IE.

We now examine a worked example of a stealth assessment of problem-solving skills that was developed and used within a modified version of a popular immersive 2-dimensional game based on the steps described above.

5.4 An Illustration of Stealth Assessment in a Game Environment

To make the process of creating a stealth assessment come alive, we present an example in which a problem-solving stealth assessment was developed and built into a game called "Use Your Brainz" (UYB; a modified version of the game Plants vs. Zombies 2; Shute, Wang, Greiff, Zhao, & Moore, 2016b). In the game, players position a variety of special plants on their lawn to prevent zombies from reaching their house. Each of the plants has different attributes. For example, some plants (offensive ones) attack zombies directly, while other plants (defensive ones) slow down zombies to give the player more time to attack the zombies. A few plants generate "sun," an in-game resource needed to utilize more plants. The challenge of the game comes from determining which plants to use and where to position them on the battlefield to defeat all the zombies in each level of the game.

To create a stealth assessment measuring problem-solving skills, Shute and colleagues first developed a competency model of problem solving based on an extensive literature review (step 1). The operationalized problem-solving CM included four main facets: (a) analyze givens and constraints, (b) plan a solution pathway, (c) use tools effectively/efficiently when solving the problem, and (d) monitor and evaluate progress. In parallel with developing the problem-solving CM, Shute and her team selected an appropriate IE (the UYB game) in which to embed the stealth assessment (step 2). They selected this game for several reasons. First, UYB requires ongoing problem-solving skills (like chess). Second, although it is a 2D game, it can provide an immersive experience in that its engaging environment requires players to continuously apply the various in-game rules to solve challenging problems. Third, this work was part of a joint project with GlassLab (see https://www.glasslabgames.org/), and Glasslab had access to the game's source code which allowed the researchers to modify the data to be captured in the log files and embed the stealth assessment models directly into the game.

After finalizing the problem-solving competency model, Shute and her team identified dozens of observable in-game indicators (after repeatedly playing the game and watching expert solutions on YouTube). The indicators are used as evidence to update the problem-solving CM (step 3; in this example step 4 was not needed). For example, the research team determined that planting three or more sun-producing plants (which provide the currency to use other plants) before the first wave of zombies arrive is an indicator of the "analyze givens and constraints" facet and shows that the player understands time and resource constraints. Table 5.1 includes some examples of problem-solving indicators in UYB.

Table 5.1 Example indicators for problem solving (from Shute, Wang, et al., 2016b)

Facets	Example indicators
Analyze givens and constraints	• Plants >3 Sunflowers before the second wave of zombies arrives • Selects plants off the conveyor belt before it becomes full
Plan a solution pathway	• Places sun producers in the back, offensive plants in the middle, and defensive plants up front/right • Plants Twin Sunflowers or uses plant food on (Twin) Sunflowers in levels that require the production of X amount of sun
Use tools and resources effectively/efficiently	• Uses plant food when there are >5 zombies in the yard or zombies are getting close to the house (within 2 squares) • Damages >3 zombies when firing a Coconut Cannon
Monitor and evaluate progress	• Shovels Sunflowers in the back and replaces them with offensive plants when the ratio of zombies to plants exceeds 2:1

The next task in the UYB project was to create a Q-matrix (Almond, 2010) with the four problem-solving facets in columns and all of the relevant indicators listed in rows (step 5; where the crossed cells contain the value of "1" if the indicator is related to the facet and a "0" if they're unrelated). Afterwards, they determined the scoring rules (step 6). This entails deciding about how to score the indicators by classifying them into discrete categories (e.g., yes/no, high/medium/low relative to the quality of the actions). For example, if a player planted six sunflowers before the second wave of zombies, the action will be automatically recorded as "yes" providing positive evidence of the first facet "analyze givens and constraints."

After categorizing all indicators, Shute and her team connected each indicator to the related CM variable(s) and established a statistical relationship between them (step 7). They used Bayesian Networks to create the statistical relationships, accumulate the incoming gameplay data, and update the beliefs in the competency model (note: they created one BN for each level, 43 BNs in total). Why were BNs used over other techniques? De Klerk, Veldkamp, and Eggen (2015) conducted a systematic literature review on various analytical approaches used in simulation-based and game-based assessments to analyze performance data (i.e., the data generated by learners' interaction with the IE). The most prevalent examples of such analytic tools include Bayesian Networks (BNs), Exploratory and Confirmatory Factor Analysis, Item Response Theory, Multidimensional Item Response Theory, Cluster Analysis, Artificial Neural Networks, and Educational Data Mining. Overall, BNs were the most used analytical and data modeling framework to analyze learners' performance data in game-based and simulation-based assessment. Moreover, there are several advantages to using BNs as a data modeling framework in IEs such as: (1) BNs provide an easy-to-view graphical representation of the competency model (direct and indirect relationships among variables) for clear operationalization; (2) BNs can "learn" from data as they're probability models (thus make probabilistic predictions)—the degree to which observed data meet expectations of the model can help improve the original model as more data become available; (3) Updating BNs is immediate (as performance data come from the IE) compared to other analytical approaches (like IRT), so they provide real-time diagnosis—overall and at sub-score levels; and (4) Enhancements to BN software permit large and flexible networks with as many variables as wanted (Almond et al., 2015). Moreover, by using only discrete variables, BNs can be scored very quickly, making them suited for embedded scoring engines.

Consider indicator #37 in Fig. 5.2 (use of iceberg lettuce in UYB). This indicator is connected to the "tool use" facet, and a player has just performed some action in the game which was judged as "poor" (e.g., placed an iceberg lettuce proximal to a fire-breathing plant, thus cancelling out the "freezing" effect of the lettuce). The real-time estimate that the learner is low on the "tool use" facet is $p = 0.61$ (for more details see Shute, Wang, et al., 2016b).

When establishing the BNs for UYB, the game experts and psychometricians in the team initially set the probabilities of the various states, per competency model variable (i.e., the prior probabilities in BNs). However, after pilot testing the BNs,

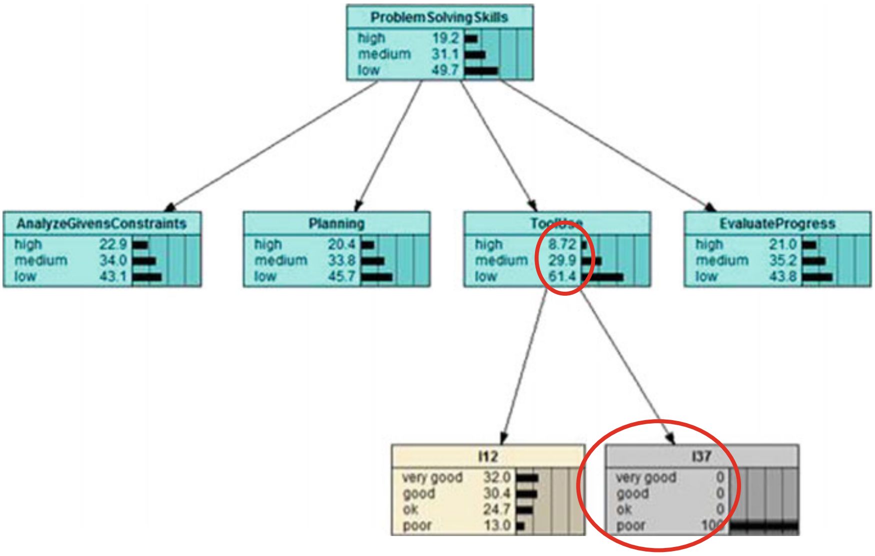

Fig. 5.2 An example of a BN with data for indicator #37 entered (poor use of iceberg lettuce)

data were used to modify the BN parameters (difficulty and discrimination) accordingly (step 8). Finally, to validate the stealth assessment using external measures (step 9), Shute and colleagues used two external measures of problem solving skill: (a) Raven's Progressive Matrices (Raven, 1941) which examines inductive ability (i.e., rule identification) based on given information; and (b) MicroDYN (Wustenberg, Greiff, & Funke, 2012), a simulation which measures problem solving skills based on acquiring and applying existing information (i.e., rule application).

Validation study participants were 7th grade students (n = 55) from a middle school in suburban Illinois. They students played the game for 3 h (1 h per day across three consecutive days). The results showed that the students' scores from the two external tests significantly correlated with the in-game stealth assessment estimates [Raven's (r = 0.40, p < 0.01) and MicroDYN (r = 0.41, p < 0.01)]. Therefore, the stealth assessment embedded in the UYB game appears to be valid. Other studies have been conducted using stealth assessment to measure various competencies, e.g., physics understanding (Shute et al., 2013) and persistence (Ventura & Shute, 2013). The overall findings from these studies also show significant correlations between external and the in-game estimates. Finally, it's important to note that this assessment approach, while illustrated in a 2D environment, can also be used in 3D games and environments (e.g., Portal 2 research, see Shute et al., 2015). We now discuss the next logical steps to take—making IEs adaptive based on assessment data.

5.5 Next Steps

After creating and embedding a stealth assessment into an IE and testing its psychometric properties (i.e., reliability, validity, and fairness), the next step is to provide adaptive or personalized learning supports (e.g., appropriate feedback and challenges) based on current estimates of competency states (Shute et al., 2017). This type of adaptation (i.e., *micro-adaptation*; see Kickmeier-Rust & Albert, 2010) keeps learners motivated to progress throughout the game/IE, engenders a state of flow, and aligns with their ZPD.

As mentioned earlier, Csikszentmihalyi (1990) asserted that when learners are fully engaged in tasks that are neither too difficult nor too easy, they enter the state of flow in which they learn best. Similarly, Vygotsky (1978) believed that the best learning experience happens when learners receive learning materials just beyond their current knowledge or skill level. Research has shown that adaptive learning activities generally yield better learning outcomes than non-adaptive activities (e.g., Kanar & Bell, 2013). We suspect that similar learning outcomes can be achieved via adaptive IEs. Moreover, learning/playing in an adaptive IE can facilitate learners' self-efficacy (Bandura, 1994) and self-determination (Ryan & Deci, 2000) because learners establish new beliefs about their personal capabilities when they progressively tackle challenges that are tailored to their current ability levels. In other words, the more learners overcome appropriately-challenging tasks, the more efficacious they feel in the IE in which they interact. The gratifying experience of efficacy makes the learners intrinsically motivated to continue facing new challenges (Klimmt, Hartmann, & Schramm, 2006).

To enhance learning—both processes and outcomes—learners' state of flow would be maintained by adjusting tasks/activities in the IE coupled with ongoing targeted feedback. In theory, this would motivate them to persist and enhance their self-efficacy (e.g., Van Oostendorp, van der Spek, & Linssen, 2013). To accomplish this goal, accurate, ongoing, and unobtrusive measurements of learners' current competency states (relative to cognitive, non-cognitive, and even affective variables) are needed to continuously adapt the IE to the learners' needs and capabilities in real-time. Research is needed on how to best prioritize the skill or affective state most in need of support.

One way to accomplish adaptation in an IE is via a task selection algorithm. For instance, Shute, Hansen, & Almond (2008) developed an adaptive algorithm that tends to select tasks for which the student has an approximately 50–50 chance of solving correctly. These tasks are likely to reside within the student's zone of proximal development (Vygotsky, 1978) and hence may be good candidates for promoting learning, particularly if accompanied by feedback. In contrast, non-adaptive (e.g., linear) IEs/games may present fixed sequences of activities or tasks, often arrayed from easy-to-difficult. This may lead to predictable and impersonal learning/gameplay experiences (Lopes & Bidarra, 2011) and perhaps boredom. Creating adaptive IEs empowered by stealth assessment is currently under development and we expect to see positive results on students' learning.

5.6 Conclusions

Immersive technologies are now available to use in formal education settings as they become more affordable. Historically, VR has been used in military training for many years, MUVEs have been around for more than fifteen years, and AR has been used in museums, factories, medical arenas, and the military since the early 1990s. Nonetheless, their use in public educational settings has not been feasible due to the cost and availability of the technologies, until recently. Currently, low-cost VR experiences are possible with products like Google Cardboard which only costs $15 and a smart phone (Brown & Green, 2016). Furthermore, according to a recent report (Adams Becker, Freeman, Giesinger Hall, Cummins, & Yuhnke, 2016), large investments are being made in the immersive media industry, and it is expected that the education sector will benefit from these investments within the next two to three years. In another report, Goldman Sachs predicted that the immersive media industry has the potential of being an $80-billion market by 2025 (Bellini et al., 2016).

Because of these trends, many companies (e.g., Facebook, Samsung, Google, and HTC) have entered the race for developing content with advanced technologies to make the immersive media experience possible for all (Brown & Green, 2016). Furthermore, industry leaders recognize the potential benefits of immersive well-designed games just as learning theorists posit that gameplay experiences in immersive environments can substantially improve learners' problem solving skills through multiple interactions with novel problem solving scenarios (e.g., Van Eck & Hung, 2010). However, there are still barriers to adopting IEs in formal education settings—mainly related to getting the assessment part right.

Our broad vision relating to assessment for learning involves the ongoing collection of data as students interact within various IEs during and after regular school hours. When these various data streams coalesce, the accumulated information can potentially provide increasingly reliable and valid evidence about what students know and can do across multiple contexts. To accomplish this goal, we need high-quality, ongoing, unobtrusive assessments embedded in various IEs that can be aggregated to inform a student's evolving competency levels (at various grain sizes) and aggregated across students to inform higher-level decisions (e.g., from student to class to school to district to state, to country).

The primary goal of this idea is to improve learning, particularly learning processes and outcomes necessary for students to succeed in the twenty first century, such as persistence, creativity, problem solving skill, critical thinking, and other constructs. Current approaches to assessment/testing are typically disconnected from learning processes. With innovative assessment technologies like stealth assessment, teachers do not need to disrupt the normal instructional process at various times during the year to administer external tests to students. Instead, assessment should be continuous and invisible to students, supporting real-time, just-in-time instruction and other types of learning support in all types of IEs.

For this vision of assessment—as ubiquitous, unobtrusive, engaging, and valid—to gain traction, there are a several hurdles to overcome. Several immediate concerns are presented here (for more details on challenges and future research, see Shute, Leighton, et al., 2016a).

1. *Ensuring the quality of assessments*. U.S. schools are under local control, thus students in a given state could engage in thousands of IEs during their educational tenure. Teachers, publishers, researchers, and others will be developing IEs, but with no standards in place, they will inevitably differ in curricular coverage, difficulty of the material, scenarios and formats used, and many other ways that will affect the adequacy of the IE, tasks, and inferences on knowledge and skill acquisition that can justifiably be made from successfully completing the IEs. More research is needed to figure out how to equate IEs or create common measurements from diverse environments. Towards that end, there must be common models employed across different activities, curricula, and contexts. Moreover, it is important to determine how to interpret evidence where the activities may be the same but the contexts in which students are working differ (e.g., working alone vs. working with another student).
2. *Making sense of different learning progressions*. IEs can provide a greater variety of learning situations than traditional face-to-face classroom settings, thus evidence for assessing and tracking learning progressions becomes more complex rather than general across individual students. As a result, we need to be able to model learning progressions in multiple aspects of student growth and experiences, which can be applied across different learning activities and contexts. Moreover, there is not just one correct order of progression as learning in IEs involves many interactions between individual students and situations, which may be too complex for most measurement theories that assume linearity and independence. So theories of learning progressions in IEs need to be actively researched and validated to realize their potential.
3. *Privacy/Security*. This issue relates to the accumulation of student data from disparate sources. However, information about individual students may be at risk of being shared far more broadly than is justifiable. And because of the often high-stakes consequences associated with tests, many parents and other stakeholders fear that the data collected could later be used against the students.

Despite these obstacles, constructing the envisioned ubiquitous and unobtrusive assessments within IEs across multiple learner dimensions, with data accessible by diverse stakeholders, could yield various educational benefits. First, the time spent administering tests, handling make-up exams, and going over test responses is not very conducive to learning. Given the importance of time on task as a predictor of learning, reallocating those test-preparation chores into meaningful pre-instructional activities that are more engaging for learners can benefit almost all students. Second, by having assessments that are continuous and ubiquitous, students are no longer able to "cram" for an exam. Although cramming can provide good short-term recall, it is a poor route to long-term retention and transfer of learning.

Standard assessment practices in school can lead to assessing students in a manner that conflicts with their long-term success. With a continuous assessment model in place, the best way for students to perform well is to engage with the content, interact with peers, and communicate ideas. The third direct benefit is that this shift in assessment mirrors the national shift toward evaluating students on acquired competencies. With increasing numbers of educators growing wary of traditional, high-stakes tests for students, ensuring students have acquired the "essential" skills needed to succeed in twenty first century workplace environments are consistent with the innovative type of assessment outlined in this chapter.

There is a need for innovative assessments given (a) the urgency for supporting new twenty first century skills, and (b) the increased availability of immersive technologies, both of which make it easy to capture the results of routine student work—in class, at home, or any place with available broadband access. One possibility is for twenty first century assessments to be so well integrated into students' day-to-day lives that they are unaware of its existence. This represents quite a contrast to our current testing contexts. However, while the benefits of using a seamless-and-ubiquitous model to run a business have been clear for more than four decades (e.g., using barcodes), applying this metaphor to education may require modifications given the desired outcome is knowledge rather than financial capital. For instance, there are certain risks to consider: students may come to feel like they are constantly being evaluated which could negatively affect their learning by causing unwanted stress. Another risk of a continuous assessment approach in education could result in teaching and learning turning into ways to "game the system" depending on how it is implemented and communicated. But the aforementioned hurdles and risks, being anticipated and researched in advance, can help to shape the vision for a richer, deeper, more authentic assessment (to support learning) of students in the future.

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Benjamin Emihovich is a Doctoral Candidate in the Instructional Systems & Learning Technologies program at Florida State University. He holds a M.Ed. from the University of Florida and a B.A. in Psychology and Social Behavior from the University of California, Irvine. He is interested in exploring how well-designed video games can be used to improve a wide range of knowledge, skills, and abilities referred to as game-based learning (GBL). His dissertation research measures the impact of video gameplay on undergraduates' problem-solving skills. Video games have broad appeal with plenty of research opportunities available to meet the demands of a diverse learner population and those at-risk of failing.

Chapter 6
Infrastructures for Immersive Media in the Classroom

John Richards

Abstract VR, AR, and MR are becoming ubiquitous in consumer gaming, military applications, and office environments. These successes are driving emerging efforts to integrate these immersive media into the K-12 classroom. In this chapter, first we summarize the distribution and availability of the infrastructure needed for using VR and MR in the schools. Using immersive media requires a technology infrastructure consisting of dependable high-speed Internet connectivity to the classroom, a ratio of at least one-to-one computer to student, an interactive white board, and curriculum materials that can be monitored and controlled by the teacher. This infrastructure is quickly becoming a reality. However, a larger and more complex barrier remains: integrating the new technologies with existing classroom systems and with existing and emerging pedagogical practice. I argue that the Digital Teaching Platform serves as a model for classroom practice. The evolving nature of digital curricula, formative assessment, and classroom practice impact how teachers will be able to integrate these new technologies. Finally, I examine how immersive media such as virtual reality, augmented reality, mixed reality, and multi-user virtual reality can work as supplemental digital materials for instruction and assessment. In particular, I focus on the sensory comfort and fidelity of interaction as these issues impact the viability of these technologies in the classroom.

Keywords Digital teaching platforms · Distributed digital curriculum Formative assessment · Real-time classroom management · VR, AR and MR in the classroom

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6.1 Introduction

The other chapters in this volume focus on "learning" in a virtual, augmented, or mixed environment. These chapters lay a research foundation for bringing the immersive[1] technologies into the classroom. However, if these new technologies are to be more than a fad or distraction, they must be integrated into a comprehensive "hybrid" curriculum that includes digital, print, and hands-on exploration. In this chapter we consider the use of digital infrastructure as the fundamental carrier of such a core curriculum, even as it is being invented.[2]

The challenge is how immersive media will fit in the institutional K-12 market. First, we look at the state of school technology to assess its support for a curriculum and a classroom that are digital at their core. Second, we introduce the notion of a Digital Teaching Platform as a framework for understanding the dynamics of introducing VR/AR/MR into a teacher-led classroom where the digital environment is the major carrier of curriculum content and provides the functions of a primary instructional environment. Finally, we look the issues of sensory comfort and the potential for the fidelity of interaction in VR, MR, and AR. The state of the art is moving quickly, but issues of nausea stand in the way of full acceptance in an institutional environment.

6.2 Classroom Technology Infrastructure

In this section, we summarize the existing distribution and availability of bandwidth, connectivity, equipment, and management systems required for supporting any digital curriculum in the classroom. Administrators want access to data and analysis, teachers want dependable class sessions, and students want universal access for lessons, homework, and practice.

6.2.1 The VR/AR/MR Industry

According to BCC Research, the global VR/AR market for Education was $548.8M in 2014, $1025.40M in 2015 and is expected to grow to almost $16B by 2020

[1]As mentioned in the Introduction, we use the term "immersive media" to refer to virtual reality, augmented reality, mixed reality, and MUVEs.

[2]We have restricted this analysis to the K-12 world. In higher education, as in the consumer market, there is ample bandwidth, students have multiple devices, and digital infrastructure is readily available in the learning environment Moreover, unlike K-12 education, higher education offers many interesting options for individual exploration and independent extension of the curriculum.

Table 6.1 Global market for virtual and augmented reality by sector (BCC, 2016, pp. 7–8) ($ Millions)

Sector	2014	2015	2020	CAGR% 2015–2020
Gaming	1404.50	2521.40	32,030.40	66.3
Military	1051.00	1839.90	20,808.90	62.4
Healthcare	636.7	1150.20	15,115.70	67.4
Education	548.8	1025.40	15,591.60	72.3
Industrial training	496.8	901.8	12,315.70	68.7
Others	362.2	661.3	9337.70	69.8
Total	4500.00	8100.00	105,200.00	67.0

(BCC, 2016, p. 7). Success at the extremes—in consumer gaming and military applications—is pushing innovation, investment, and lower prices for VR/AR/MR. Interestingly, the Education market is consistently is larger than the Industrial Training market (see Table 6.1).

Immersive media require dependable high-speed Internet connectivity, at least one-to-one device to user ratios, interactive displays, and digital materials that can be monitored and controlled locally and dynamically. Until recently, almost none of this existed in K-12 education environments. However, what is becoming ubiquitous in the consumer and office environments is rapidly emerging for K-12.

6.2.2 Classroom Infrastructure

In 2004, the World Summit on the Information Society (WSIS) established goals in order to "enhance the development of a global information society" [ITU, 2014, p. 1]. In particular, one of the four key goals was, "adapting primary and secondary school curricula to meet the challenges of the information society" [ibid, p. 2]. This was translated into the second of eleven targets: "Connect all secondary schools and primary schools with information and communication technologies" (ITU) [ibid]. One of the indicators that is relevant to VR/AR is the proportion of schools with Internet access.

6.2.2.1 Internet Access for Schools

The proportion of schools with Internet access is near 100% in Europe, North America, and the OECD (ITU 2014, pp. 72–3). In addition, according to the U.S. Department of Education, in the U.S. as of 2008 (the last year for which data was collected) 98% of classrooms had Internet access (Digest, 2016, p. 231), that would be effectively 100% by now.

6.2.2.2 Device to Student Ratios

The second WSIS indicator is the learners-to-computer ratio. Assuming the need for at least one-to-one device per student ratio for VR/AR, this is critical for implementation. The learners-to-computer ratio is lowest in North America, Europe, and other OECD countries, and highest in developing countries (ITU, 2014, p. 51) (see Figs. 6.1, 6.2 and 6.3).

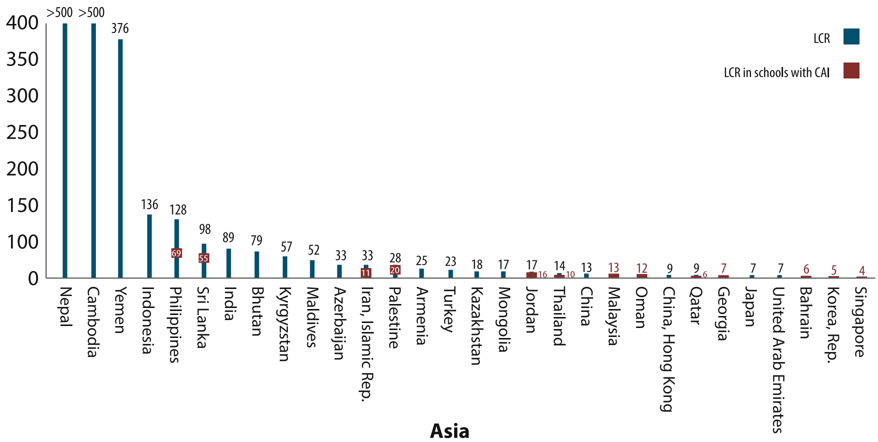

Fig. 6.1 Learner to computer ratio, Asia [ITU, p. 66]. *Source* UIS database, Partnership on Measuring ICT for Development WSIS Targets Questionnaire, 2013

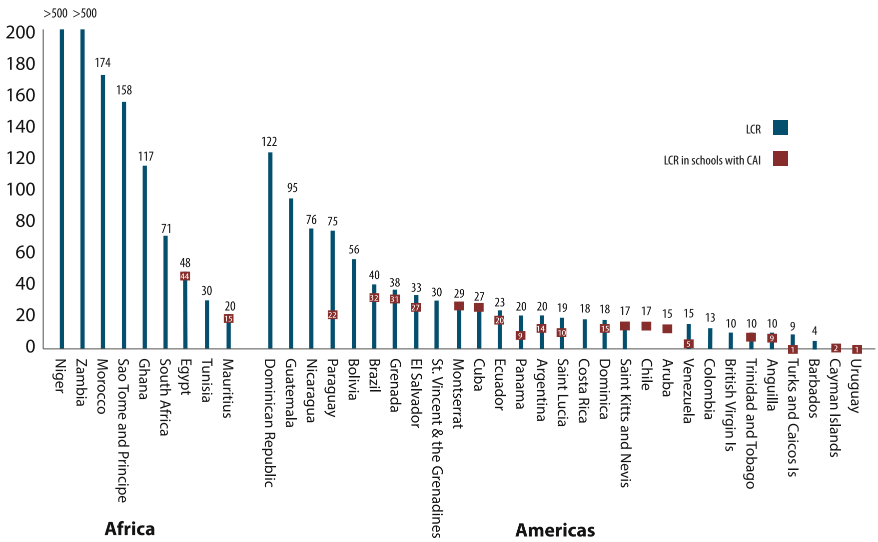

Fig. 6.2 Learner-to-computer ratio, Africa and the Americas [ITU, p. 67]. *Source* UIS database, Partnership on Measuring ICT for Development WSIS Targets Questionnaire, 2013

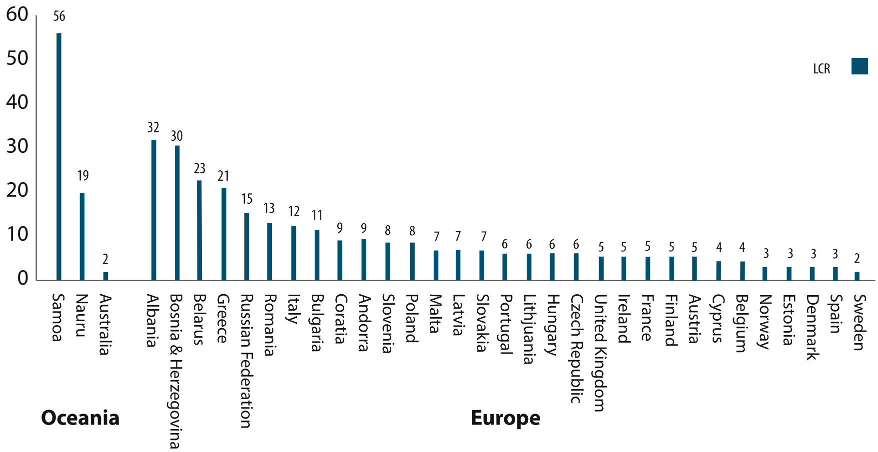

Fig. 6.3 Learner-to-computer ratio, Oceania and Europe [ITU, p. 67]. *Source* UIS database, Partnership on Measuring ICT for Development WSIS Targets Questionnaire, 2013

It is important to note that these figures are from a 2014 report, and the data comes from several years before that. There have been significant reductions in the cost per device since the time of the actual survey. As a result we believe the ratio of students to device are lower.

6.2.3 Interactive Displays

The shift to Chromebooks, tablets, and smartphones also has an immediate impact on the classroom. comScore reports that, in the U.S., "total digital media usage" nearly tripled between 2010 and 2015, with smartphone usage accounting for most of this. In the two years between December 2013 and December 2015, the report cites a usage increase of 78%. Tablets grew 30% over this two year period. (comScore, 2016, p. 5). While this data is restricted to the U.S., in my judgment the switch to smartphones and tablets is clearly a global phenomenon. According to IDC, Samsung and Apple are the global leaders in the Smartphone market (IDC, August 2015).

According to Market Data Retrieval, 69% of districts in the U.S say they have "substantially implemented" interactive white boards, and 69% say they have "substantially implemented" the standard projector (MDR, 2015, p. 65).

6.2.4 Digital Management Systems

As we have seen, the technological infrastructure for the print-to-digital curricular transition is mostly in place: bandwidth, connectivity, access to devices from computers to tablets to smart phones, and interactive whiteboards. In addition, there has been a significant investment in enterprise management systems including learning management systems (LMS), student information systems (SIS), and (although lagging behind) data warehouse and analytics systems. This is certainly enough to support the basic transition from print to digital curriculum; but, as we shall see in the next section this transition requires much more.

6.3 Modelling the Digital Classroom

To better understand the dynamics of the device-intensive, networked, digital curriculum classroom, we present a model for the role of digital media in the classroom. The Digital Teaching Platform (DTP) is a model of school based learning designed to bring interactive technology to teaching and learning in classrooms in which each student and the teacher has a laptop, or some equivalent computational device, connected to the network (see Dede & Richards, 2012).

The very personal and immersive technologies that enrich the student's experience by their very nature separate the student from the classroom environment. There is precedent for this in the financially successful, but pedagogically limited "Integrated Learning Systems" (ILS's) of the '80s and '90s. ILS's provided one-on-one tutoring. Students had their own computer with headphones. This separation of the student meant that the ILS's were relegated to separate computer labs or to a couple of computers in the back of the classroom. In either case, students were pulled out of the curriculum, and the lessons were claimed to be "teacher-proof." For many reasons this approach failed, but from our perspective the most significant is that it ignored the central role of the teacher in the school. As with all classroom media, the teacher needs to be engaged, to understand when to use these, for which students, and under what circumstances.

For VR/AR/MR to succeed in the institutional setting it must be incorporated into the school culture, and treated like any other supplemental curriculum component. It must meet the demands of the school environment. In particular it must be:

- Aligned to curriculum standards;
- Compliant to technological standards;
- Integrated into the curriculum;
- Linked to formative assessment; and
- Supported by professional development.

6.3.1 *Digital Teaching Platforms*

DTP is a model of school-based learning experiences. The model provides a framework to understand the dynamics of a teacher-led classroom where the digital environment is the major carrier of curriculum content, and functions as the primary instructional environment in today's technology-intensive classrooms. There are two feedback loops in the model. The main classroom loop displays the dynamic between the teacher, students, and curriculum. This is a continuous feedback system as the teacher manages the classroom, facilitates learning, and monitors student progress. The inner, technology-intensive personalized practice loop is individualized dynamically for each student (Fig. 6.4).

A full-fledged DTP addresses three major requirements of contemporary classrooms: **First**, a DTP models a completely realized, networked digital environment that includes interactive interfaces for both teachers and students. Teachers use the administrative tools of this digital environment to create lessons and assignments for students and to manage and evaluate the work the students return. A DTP includes specific tools for assessment: for creating tests, assigning them to students, and reviewing the results. The teacher tools also provide timely reports on student progress or their remedial needs. The administrative tools for students allow them to complete assignments and assessments. More importantly, these tools allow for both individual and group work. Some students can work independently on individualized assignments, while others can work collaboratively on shared assignments.

Second, a DTP provides the content of the curriculum and assessments for teaching and learning in digital form. This content includes all of the information in the curriculum, the instruction, the exercises, and the assessments. The content also includes interactive elements, manipulative activities, special-purpose applications, multimedia materials, and so on.

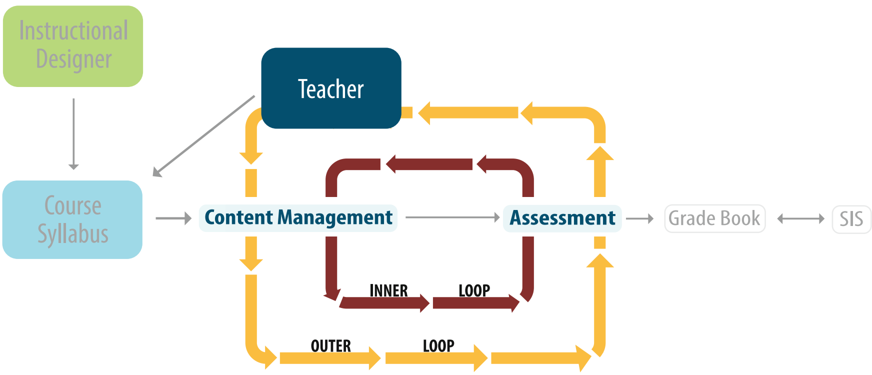

Fig. 6.4 The inner Assessment-Content Management loop provides personalized practice. The outer curriculum loop provides space for VR/AR/MR applications

Third, a DTP supports real-time, teacher-directed interaction in the classroom. It includes special tools for managing classroom activity; for monitoring progress on assignments; for displaying student work, demonstrations and challenges on interactive displays; for managing group discussions; and for coordinating all large-group and small-group activities.

All of these capabilities of a DTP are designed to function effectively in the give-and-take atmosphere of a regular classroom. The teacher can shift quickly from large group demonstrations, to small group activities, to individualized practice and assessment. Students move seamlessly from using their devices for some of these activities to closing their computers and participating in discussions. The teacher is fully in control of student activities by making assignments, mentoring individuals, and leading discussions. In DTPs, the pedagogy of the curriculum is designed using principles of guided social constructivism as a theory of learning, and the system provides the support for a transformation of teaching and learning.

The teacher, as facilitator, is a demanding role. We speak of this as understanding the choreography of the classroom—the movement of the teacher:

- From the desktop and interactive whiteboard;
- To the small groups collaboratively solving problems;
- To the half-class lesson;
- While managing individuals practicing their individualized problem set.

Being the "guide on the side" is a new dynamic for many teachers and the DTP needs to provide scaffolding for the teacher in this role.

The DTP model incorporates a curriculum model, an assessment model, an instructional model, a classroom management model, an infrastructure model, and a policy model (at minimum). In the next two sections we look at the digital curriculum, and the assessment models. When we present the classroom architecture, we look at models for instruction, classroom management, and infrastructure.

6.3.2 Curriculum

The digital curriculum has the potential to provide the student, or students, with exploratory environments that can challenge their curiosity and creativity. The teacher can pose problems for the class, or a part of the class on the interactive white board. These fit the classroom just as the manipulatives have, and the science laboratory. This requires that the curriculum move far beyond the e-book page turner. Simulations, time line tools, geographic information services, can bring the world into the classroom to engage the student.

The traditional curriculum, as expressed in textbooks, is created once and preserved in the print copies. Traditionally, particularly in adoption states, warehouses were required to store enough copies to cover seven years usage. The result is a stagnant, fixed document that is not subject to change. Teachers did modify the curriculum by adding supplemental materials, by omitting sections of the text, or by changing the order.

In contrast, digital curricula are distributed to each device in the classroom. In so doing, there is the possibility of personalization at several levels. The teacher can modify the curriculum as was done with textbooks, but in addition the actual materials could be selected for any individual student, or for a group of students. This could be done by the teacher by modifying lessons, by the formative engine adjusting to student performance, or, potentially, by the student seeking deeper materials as part of a project, or more or less challenging materials in practice.

The ability to modify the curriculum applies not only to the depth that the main curriculum provider supplies, but also to the inclusion of supplemental materials. These are traditionally videos, media, interactive learning objects that promote exploration and challenge the students. This is where AR/VR/MR can be integrated into the existing curriculum.

The challenge is to allow the system to accept these additional materials. They must be aligned to the curriculum and appropriate standards, metadata must be commensurate with the system, and the teacher has to know when they would fit with the lesson.

6.3.3 Assessment

The traditional Learning Management System (LMS) maintains a close connection between content delivery and student assessment. The LMS model invoked a constrained curriculum delivery with regular feedback from the assessments for learning, as seen in Fig. 6.5.

The nature of the assessment in the traditional LMS is summative. At the end of a curriculum unit there is a test with a mapping either back into the unit or on to the next unit. The metaphor is that there is a “boxcar” of content, and the assessment looks at the student as they enter and leave this boxcar. While this inner loop looks the same in a DTP, the nature and purpose is quite different. First, the LMS content

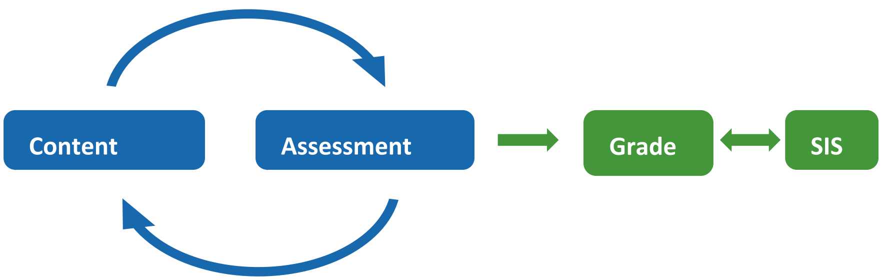

Fig. 6.5 Testing—curriculum practice loop

is the curriculum with the intent to provide instruction. In the DTP, the content is clearly practice, and the purpose is to provide this practice in support of the classroom instruction. The assessment is ongoing formative assessment that is constantly interacting with the student's performance.

6.3.4 Classroom Architecture

The basic architecture is constructed around a Digital Asset Manager that provides access to tools, and a variety of libraries of lessons, projects, videos, graphics, and simulations. All of this is integrated with meta-data to connect to standards and an assessment engine. Multiple curricula can be constructed in this environment. The classroom functionalities are controlled by a Student-Facing App and a Teacher-Facing App (see Fig. 6.6).

The Student Facing App gives the student access to challenging, interesting, and dynamic content. The VR experience is part of a full complement of media for the student to explore and analyze. This is the heart of the student-centric pedagogy that changes the dynamic of the classroom. In addition to interactive lessons, the student will also have access to basic tools such as journaling, planning, access to feedback from the teacher or other students, and assignments. The student needs a workspace/lab to assemble assignments. This should allow the ability to take screen snapshots of work and incorporate into their journals or assignments.

The Student-Facing App provides the student with:

- Lesson/Tools Interaction
- Content Sequencing
- Assignments
- Assessment

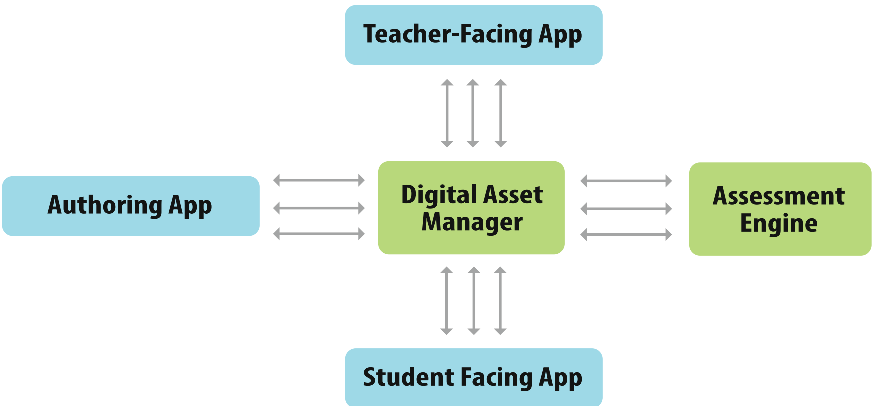

Fig. 6.6 Classroom side of the DTP architecture

- Progress Reporting
- Social Networking/Communication.

The Teacher-Facing App gives the teacher control over the classroom and the ability to monitor, adapt, and modify the curriculum. The structure of lessons must be completely transparent so that the teacher can modify parts of a lesson. As a part of teachers' lesson planning and classroom management they should have access to a dashboard that provides information on any individual student as well as cross-class information about specific topics. The teacher needs to be able to assign different sets of materials to different students.

An important part of the teacher's ability to modify lessons is a Lesson Planning tool that provides a framework for planning curriculum (calendar, plans for a day including sequencing activities, and differentiation of instruction and materials). Thus, the Teacher-Facing App provides the teacher with:

- Real-Time Classroom Management
- Lesson Planning/Calendar
- Assessment Tools
- Reporting
- Social Networking/Communication
- Tools for Managing Students and Classes
- Dashboards and Tools to Review Student Progress, Work, and Performance.

6.4 Special Considerations for Using VR/AR/MR[3]

This section expands upon the concept of *comfort* (see Jacobson, Chap. 3), which is important with any media. The user experience should be comfortable and efficient, providing a seamless experience. This essential with immersive media, especially VR and MR, because they depend on creating sensory effects that closely mimic or parallel effects in the real world. Most of these effects are triggered by user actions, especially when s/he looks in a particular direction, uses the controls to navigate (in VR), or uses the controls to manipulate a virtual object.

There are literally decades of literature on best practices with VR engineering and human factors (Kronqvist, Jokinen, & Rousi, 2016) (Oculus, 2016). Here, we will present some of the most important factors for immersive media, especially those that cut across the sub-media types.

[3]The author wants to acknowledge Jeffrey Jacobson who contributed significantly to this section.

6.4.1 Field Of View (FOV) and Field Of Regard (FOR)

Humans have approximately a 180°–200° horizontal field of view, but only approximately 30° in the center of that comprises our highly detailed central vision. The rest is peripheral vision, which sees much less detail, is less sensitive to color, but is *more* sensitive to motion.

The wider the FOV in the VR display, the more realistic and comfortable the experience will be, if other aspects of the display are managed well. It allows the user to spend less time looking around and to see more things in relation to each other. Fortunately, today's commodity head-mounted displays provide a 90° field of view, which is acceptable. Their main strength is a fully 360° field of regard, which lets the viewer look in any direction. The visual cortex does an excellent job of effortlessly stitching together what the eye sees, as the user looks around, providing a panoramic sense of the virtual world.

Field of View is also important in AR applications, because it limits what you can add to the physical world. When the user of a head-mounted AR display turns their head past the FOV capability of the device, the AR objects disappear, which usually breaks the illusion. Unfortunately, this is true of most MR capable headsets available to the public.

Typically a cave or dome has a field of view at least 180°; this is often wider horizontally and vertically in the case of a dome or a CAVE with the ceiling. They rarely include a projection onto the floor, however, and the user always has a number of stable objects around them to remind them that they are still in the physical world.

6.4.2 Fast View Update for HMDs

As we discuss in the introductory chapter, a head mounted display (HMD) allows the user to look in any direction and see one of three things: a completely virtual reality (VR), a mixed reality (MR), or a panoramic film, also known as 360 film. For this to work, the user's view must update immediately, with no lag or jitter. The image should be refreshed at 90 frames-per-second or better. Otherwise, it breaks the illusion of being in the virtual space (VR or film), or the virtual objects appear to float strangely (MR).

Unfortunately, designers tend to build too much into their VR environments or their AR objects. The temptation to add more geometry, more textures, and more of everything is nearly irresistible. The result is a poor frame rate, which is unacceptable. One advantage of 360 films is that anything the camera can capture can be represented, with no effect on how quickly the image refreshes.

Interestingly, even the worst dome theaters and CAVEs do not have this limitation, because all the pixels in the panoramic view are there to be seen in the single view. The view must only refresh at a minimum of 30 frames per second (fps), as they would in a typical movie theater. The downside, of course, is that the view is always less than 360, often much less. Similarly, when Mixed Reality (MR) is implemented with projectors that add digital objects to the physical world, they only need 30 fps to look stable, as with any other projection.

6.4.3 Motion Sickness in Virtual Reality

This has always been a major problem for VR applications, and to some extent always will be. It arises from a basic sensory conflict, where some sense report to the brain that the user is moving through the virtual environment while others report that s/he is not moving at all. Cataloguing all the factors is beyond the scope of this article, but the most important ways to reduce motion sickness are (1) fast view update (2) otherwise good quality image (3) minimize use of continuous movement, in favor of jump or teleport, (4) and much more. See Lawson (2014) and Davis, Nesbitt, and Nalivaiko (2014) for more information.

6.4.4 The Registration Problem in Mixed Reality

The hardest thing in Mixed Reality (MR) is called the *registration problem*, which refers to making the digital objects apparently stay in one place in relation to the physical world. The device has to somehow be aware of the user's location and direction of gaze on the real world. Then it redraws the digital object(s) in the correct physical location 90 times per second,[4] regardless of how quickly the user is looking around and/or moving.

Lower-end AR applications can use a simple camera, like the one on smartphone, but this is reliable only when it has a high-contrast symbol to lock onto. This supports many useful applications, but is ultimately quite limiting. More advanced tools analyze the geometry of the physical environment, either using the camera or Lidar, infrared, or some other scanning technology. All of these solutions require a great deal of processing power, which makes fast updates difficult. There has been a great improvement recently, with displays such as the Microsoft HoloLens, the Google Tango, and Meta glasses, with many others on the horizon. Nevertheless registration remains a difficult problem and will be an obstacle for some time.

[4]This standard is somewhat subjective. 90 frames per second is acceptable, today.

6.4.5 Fidelity of Interaction

If the user is expected to interact with the experience, then the application must be extremely responsive, which is challenging in VR and MR. If the device is tracking the user's body, it must be accurate and precise. The interaction between the body and the virtual objects must also be crisp and accurate. Even when the control devices are "Low-end" or primitive, such as using an Xbox 360 controller to navigate, that interaction must also be responsive and carefully tuned.

Interestingly, users "holding" a virtual tool will tolerate a great deal of indirection between their hand and the business end of the tool. It can look completely different from the tracked object they are holding, it can move at a different scale, and it can be oddly shaped. Nevertheless, people are able to use the tool effectively, as long as the interaction is crisp and they can see the results. This is because hand-eye coordination and other capabilities that the brain employs for tool using are very highly developed in humans.

6.5 Conclusions: The Impact and Viability of AR, VR, and MR in the K-12 Classroom

Even though research has been conducted for over twenty-five years, we have not seen large-scale successful applications of immersive learning technologies in the classroom. The other chapters in this volume are documenting successful learning episodes using these technologies. I have argued that the move from learning to institutional acceptance requires infrastructure, which is becoming a reality, and a model for the successful implementation of digital curriculum, a Digital Teaching Platform.

The DTP classroom architecture provides the support for the teacher to expand the curriculum. If the student spends time in a virtual world, that experience must be coordinated with the rest of the instructional process. The VR experience provides content and motivation, but the tools of the classroom promote reflection, and communication. In this regard, VR functions very much like simulations in various disciplines, or manipulatives in mathematics. Integration into the tools of the curriculum makes the learning possible.

While VR is inherently isolating in its current instantiations (with the potential exception of MUVE's), AR actually has the potential to fit quite easily into DTP environment. To begin with, AR can easily support teams of students working together to solve a problem—as happens in Pokémon GO. A student or team can explore their environment: recording readings of temperature, or PH; moving about in a museum augmented by information; or moving about town in search of an artifact. In Augmented Realities such as these, interesting artifacts and data can be saved in a database, or collected in a spreadsheet. If the student wants to analyze the data collected, then tools to assist in that analysis are necessary. Finally, presentation capabilities would allow the student or team of students to share their results with the class. Overall, the teacher must be able to fit this experience into the different paths through the curriculum.

I believe that the success of these technologies in other domains, combined with the presence of the digital and pedagogical infrastructure for the classroom, suggests that it is time to move from research to practice.

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Chapter 7
The Potentials and Trends of Virtual Reality in Education

A Bibliometric Analysis on Top Research Studies in the Last Two Decades

Dejian Liu, Kaushal Kumar Bhagat, Yuan Gao, Ting-Wen Chang and Ronghuai Huang

Abstract Virtual reality has gained worldwide interest among the researchers in the field of educational technology recently. This chapter presents an overview of virtual reality research in education and also a bibliometric analysis was performed to evaluate the publications on virtual reality from 1995 to 2016, based on the Thomson Reuters's Web of Science (WoS). A total of 975 related documents were analyzed based on their publication patterns (documents types and languages, major journals and their publications, most prolific authors, most productive journals and their publications, and international collaborations). Bibliometric results show that the number of article has been increasing since 1995 exponentially. USA, UK and Chinese Taipei are the top 3 most productive countries/regions which are involved in virtual reality research in education. The findings would help the researchers to understand current developments and barriers in applications of virtual reality in education.

Keywords Virtual reality · Education · Bibliometric analysis

7.1 Introduction

With the prosperity of technology and the sustained progress of society, there are an increasing number of science fiction scenes starting to come in our real life. For instance, the breakthrough of stimulation technology and the improvement of devices

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make individuals difficult to distinguish the virtual environment from real world. In fact, a continuum of real-to-virtual environment (Milgram & Kishino, 1994) rather than a dichotomy of real world or virtual environment has been taken into consideration for the epistemology about the world, because of the development of science and technology. There are both an augmented reality environment which is closer to reality and a virtual reality which is similar to total vitality. Nevertheless, the augmented reality and the virtual reality have plenty of similarities in technology characteristics and practice application, the augmented reality, to some extent, could be even considered as a subtype of virtual reality. Therefore, this chapter will discuss the continuum environment in between based on virtual reality with a broader sense.

As one of the great progress in technology which will lead to the dramatic changes in life style and organizational structure that humans have become accustomed with, virtual reality (VR) takes unprecedented scenes into many fields, especially education. Although it is just starting to scratch the surface in educational applications, many researchers believe that VR has great potential for positive educational outcomes (Bujak, Radu, Catrambone, Macintyre, Zheng & Golubski, 2013). VR is able to be considered as a mosaic of technology, supporting for the creation of synthetic and stimulating a high level of interactions in both real environment and three-dimension context (Mikropoulos & Natsis, 2011). The use of VR in education does not only facilitate students' motivation to participant in learning activities but also promotes their ability of exploration and state their own points of view (Dalgarno & Lee, 2010). Pantelidis (1993) pointed that the main reasons for exploiting VR in the classrooms are the appeal for students to learn actively, high level of interaction, and individualism learning style. A majority of researchers and teachers have taken VR as a promising tool for improving the effects of education and promoting the learning outcomes overall.

Nowadays, plenty of educational products based on VR technology such as software and applications emerge in an endless stream, making researchers and educators overwhelmed. In order to make VR more effective on education, it is very essential to figure out some important questions related to VR firstly, such as the definition and characteristics of VR, its related learning theories, and its current application status in education.

7.1.1 Evolution of VR

Sutherland (1965), the father of computer graphics, put forward the basic thoughts and classical description of VR at first. He then created the first Helmet-Mounted Displays (HMD) and head tracking system in 1968, which was the embryonic stage of VR. In 1980s, some typical VR systems began to appear gradually. For example, the VIEW system developed by NASA's Virtual Planetary Laboratory included the devices like data gloves and head trackers. Foley (1987) comprehensively discussed the concept, interface hardware, human-computer interactive interface, application, and development and perspectives of VR in his article of "Interfaces for Advanced

Computing". Based on the previous studies, Lanier (1989), for the first time, proposed the term of Virtual Reality and developed the VR technology to be relevant products, promoting the development and application of VR. Since 1990s, with the continuous development of technology, the simulation and emulation environments based on VR extended to border areas from the pure research in laboratory, including military, science, engineering, education and training, medicine, business, art, entertainment, and other fields. With the industrialization and commercialization of VR technology in past two decades, 2016 was considered as the Year of VR technology because many giant companies shift sights to the development and application of VR, pushing VR into a new stage of comprehensive development.

Although VR has emerged for more than half a century, it has yet reached a consensus on the definition in field. In general, the definition of VR can be elaborate from two perspectives: technological perspective and psychological perspective (Coelho, Tichon, Hine, Wallis, & Riva, 2006). From the technological perspective, VR is a collection of diverse technologies with interactive means (Coelho et al., 2006). Specifically, VR integrates a set of multiple media in a three-dimensional environment such as audio, text, video, image, and so on. The difference of VR from the traditional multimedia lies in its interactive characteristic (Riva, Waterworth, & Waterworth, 2004). Therefore, VR can be defined as a three-dimensional computer generated environment, which integrates diverse technologies, updates in real time, and allows human interaction through various input/output devices (Boud, Haniff, Baber, & Steiner, 1999).

From the perspective of psychology, VR was defined as a particular type of experience instead of a technology (Coelho et al., 2006). Through connecting the computers to one another via the Internet, several users are allowed to simultaneously participate in the same VR environment, engaging in a diverse set of social interactions as well as creating different types of virtual contents (Nagy & Koles, 2014; Spence, 2008). Therefore, the interaction with the synthetic world, which projected by VR, offers the people a feeling of immersion, which is not a technological component but a result of the interaction between man and environment (Coelho et al., 2006). In addition, as another essential concept for people to have a clear understanding about the psychological definition of VR, presence refers to the user's subjective psychological response to VR (Bowman & McMahan, 2007), being as an experience common among different types of human experiences independent of any technology (Coelho, et al., 2006). It is the psychological sense of "being there" in the environment generated by VR. Users tend to behave as if they are in the real life situation though cognitively they know they are not (Lee, Wong, & Fung, 2010). Lombard (2000) even argued that the fundament of presence in the immersive environment is that users fall to understand the role of technology in his experience.

In summary, VR is a collection of diverse technology while it is more likely an immersive experience with the sense of presence in learning.

7.1.2 The Main Types and Characteristics of VR

Many researchers tried to classify the types for various VR produces emerging in the market. Papagiannidis, Bourlakis, and Li (2008) divided VR system into two different types: game-oriented VR such as World of Warcraft, and socially-oriented VR such as Second Life. Game-oriented VR has precise rules and regulations, limiting the availability of certain activities exclusively for specific characters while socially-oriented counterparts grant their users practically unlimited freedom and options to create their characters and to engage in virtual activities (Nagy & Koles, 2014). Based on the five-element typology of virtual communities suggested by Porter (2004), Messinger, Stroulia, and Lyons (2008) extended the typology to a border area, proposing a 5P model to classify different VRs. The 5P model included (1) purpose, which refers to the content of interaction; more specific, whether there is a specific purpose for the information or content being communicated among the virtual community on a domain, (2) place, which refers to the location of interaction. Besides determining the environment to be completely or partially virtual, whether the users are collocated or geographically disperses also needs to be considered, (3) platform, which refers to the design of interaction, focusing not only on synchronous communication, asynchronous communication, or both, but also on various platforms from Desktop VR to various VR platforms, (4) population, which refers to the pattern of interaction, focusing on distinguishing characteristics of the target user market besides on the size of the user group, and (5) profit, which refers to the return on interaction, focusing on the way to obtains the economic gains using VR from users. Some new taxonomy of VRs were also proposed in a more specific domain. For example, in the field of education, Duncan, Miller, and Jiang (2012) indicated a taxonomy from six aspects: (1) population, i.e. who the users are and the disciplines; (2) educational activities, i.e. what activities the users are performing; (3) learning theories, i.e. why the users are doing particular activities; (4) learning environment, i.e. where the users are working; (5) supporting technologies, i.e. how the system supports the users; and (6) research areas, i.e. other cases of learning specific research.

Through the development of technology and the increasing number of applications based on VR, the main characteristics of VR has been explored and discussed by many researchers. The most widely acknowledged concepts of all came from Burdea and Coiffet (2003), who used three "I"s to identify the main characteristics of VR technology: Immersion, Interaction, and Imagination. Immersion refers to the immersive experiences of being there in the virtual environment with computer-generated 3D images. Immersion mainly comes from multiple representations and sensory simulations, from visual perception to auditory, tactile, olfactory, gustatory, and motion perception. Baños et al. (2004) indicated that VR are immersive 3D environments which are able to induce a stronger sensation of presence. Immersive experience may also be induced by the other characteristic of VR—Interaction, which means that VR system can detect users' input signals and make response immediately. People could use some sensor equipment to interact with objects in virtual environments with more natural ways as in the real world, for instance, to "control" virtual objects directly by hand, and to receive force and tactile feedback from them. Dawley and Dede (2014) pointed that VR offers communication options for the users, who in virtual worlds can engage in real-time and synchronous interactions (Nagy & Koles, 2014). Subsequent researchers further extended the definition of Immersion from users' interaction with the environment and the objects within it to the interactions between different users. Therefore, virtual environments usually include social elements like "avatar" and "messaging services". Avatars are the user's representation, which serve as visual interactive chat tool for users to communicate with one another (Hew & Cheung, 2010). Through avatars users can make real for their engagement with a virtual world (Biocca, Harms, & Burgoon, 2003; Taylor, 2002). Imagination contributes to the last main characteristic of VR, which refers to a brand new approach and means provided by VR technology for people to learn the world and imagine the things that do not exist in the real world, increasing perceptual and rational knowledge, deepening understanding of concepts, and triggering new associations. However, currently, few empirical researches could verify whether VR technology can facilitate users' creative thinking and their creative activities. The specialized presentation of abstraction symbols by VR technology, on the other hand, may limit learners' imagination, making the mental models constructed in users' minds more homogenized and hindering their creativity in the context of open-ended questions. For instance, in a creative writing course, students are required to describe the future cities. If students have roamed in a virtual future city, their descriptions would be quite similar to the objects and scenes that they have just seen in the virtual city.

In conclusion, immersion and interaction are considered as the most important and the most widely accepted main characteristics of VR. Immersion focus on verisimilitude and multiple simulations of the environment, while the latter focus on the natural interaction in VR environment and interpersonal interaction between different users.

7.1.3 VR in Education

VR has been considered as one of the most potential and promising tools to promote learning outcomes as mentioned above, there is a need to know how to use VR in education and have a quite look about the applications that has been exploited in classrooms with positive effects.

7.1.3.1 VR Related Learning Theories

The prerequisite for an effective educational application based on VR is its pedagogical approach and the learning theory that follows in order to fulfil the educational goals and reach the desirable learning outcomes (Mikropoulos & Natsis, 2011). However, the absence of learning theories is common in designing and developing VR products used for education, neither the rational of design nor the user experience being considered. In fact, one of the significant challenges to develop and to use VR in education is understanding the pedagogical and learning theories that should inform the design and use of these VR systems (Fowler, 2015). First, the key theoretical basis for applying VR on education is constructivism. The constructivism suggests to take students as center in learning and teaching, not only asking students to be the active body of information processing and meaning construction, but also requiring teachers to be the guide rather than the instructor of learning (Cunningham & Duffy, 1996). The contexts, activities, and social interactions in the learning environment with constructivism keep challenging the learners' experience stored in their minds, promoting the construction of new knowledge. A series of instructional strategies extended from constructivism, such as situated learning, experiential learning, and collaborative learning, could be applied into the teaching and learning in VR environments since they have the similar features with VR.

A second learning theory related to educational VR is autonomous learning (also known as self-directed learning or self-regulated learning), which refers to a situation where learners set their learning goals, select their learning methods, minor their learning progress, and assess their learning outcomes when acquiring knowledge (Zimmerman, 1994). In autonomous learning, the process of students' autonomic exploring for knowledge construction is more important, teachers playing a guiding role. Therefore, students should use the feedbacks from teachers or environment to understand learning targets and acquire the ability of problems solving. VR technology provides resources necessary for autonomous learning, allowing students to select suitable learning environment based on their learning requirements, to take an unlimited number of repetition and practice, and to check learning outcomes by receiving feedback from environment. However, VR learning environment has a higher requirement for students' self-control ability. Teachers are quite hard to minor students' all learning behaviors in VR environment compared to the face-to-face teaching and observation currently, especially for the students wearing immersive output devices like head-mounted displays.

In this chapter, cognitive load theory (CLT) contributes to the last theory related to using VR in education. CLT is a learning and instruction theory established to coordinate instructional procedures with human cognitive architecture, with a limited working memory being as the center (Sweller, 2003, 2004). Cognitive load refers to the entire load imposed on working memory during human mental activities, such as problem solving, thinking, reasoning, and so on. Different types of cognitive load distinguished by CLT are associated with different instructional designs and various cognitive load effects. When the amount of mental load exceeds the capacity of working memory, overload will happen and mental processing activities will be interrupted. The focus of cognitive load theory, therefore, is on recognizing the role of working memory in cognitive process and making sure that the cognitive load is to be controlled within the capacity of working memory.

By multimedia modes, VR technology creates the learning environments with multiple information delivered by different sensory modalities, such as sound, images, texts, tactile cues, and even the simultaneous combinations of multiple information. On the one hand, VR creates a highly realistic world, helping learners to have an immersive learning experience; on the other hand, however, multiple modalities of information and rich stimulation may lead to the working memory overload in unit time and thus influence learning outcomes. Moreover, the impropriate environmental settings and learning scripts may hinder students from devoting their limited cognitive resources into the activities related to real learning objectives. For example, multi-sensory stimulation in VR environments may induce split-attention effect that students only focus on a certain stimulator and thus ignore the real learning objective. Another example related to cognitive overload in VR environments goes to the redundancy effect which may take place when using multiple modalities of information on the same object in order to improve students' presence and immersive experiment (e.g. the picture and words with the same meanings appearing at the same time). Therefore, the content construction and material presentation of VR learning environments should take account of cognitive theories so as to suit learners' cognitive processing and enhance learning outcomes.

7.1.3.2 Application of VR on Education

At present, the application of VR technology in the field of education is still on the progress of preliminary attempt, and yet brought into the conventional classrooms on a large scale. However, because of its characteristics of immersion and interaction, VR has broad prospects for application in different subjects. VR can create various virtual learning environments, particularly for the objects which are difficult to touch or even do not exist in the real world. Based on a number of previous studies, we divide the application of VR technology in education into four types: observational learning, operational learning, social learning, and academic research. In the practical application, these four types are not mutually exclusive; instead, they can be combined to use in a same virtual learning environment.

Observational Learning

The learners' movement and behaviors can be extended into a 3D space with VR technology. Learners are able to freely navigate in virtual environments, and obtain initiative feelings for the things inside from different spatial perspectives. Learners could, therefore, have a deeper understanding of the characteristics, construction, and relevant processing of learning targets. In this chapter, the learning activities carried out through multiple spatial special perspectives in a 3D virtual environment is summarized as observational learning. The virtual campus is one of the earliest application areas of VR technology, which stimulates the real campus using the 3D virtual technology (e.g., Sourin, Sourina, and Prasolova-Førland (2006) for the

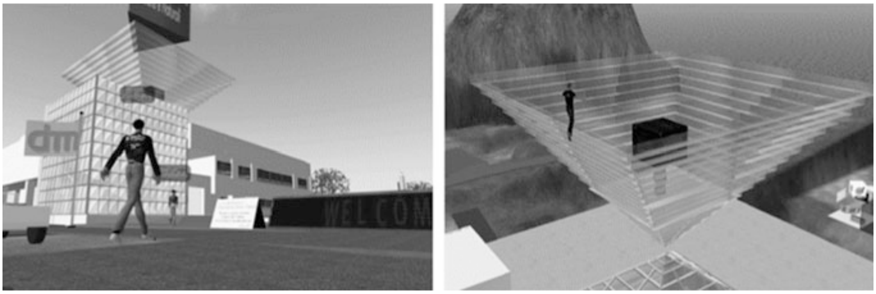

Fig. 7.1 Virtual Campus (De Lucia et al., 2009)

virtual campus of Nanyang Technological University), and includes four types of virtual space: public space, cooperate space, classrooms, and entertainment space. The virtual campus can help students be familiar with the campus environment as well as university facilities before they enter into the university, increasing their adaptation ability to university life. The virtual campus also supports synchronous lectures, rich plugins which can be added into the system boosting the interaction between teachers and students (see Fig. 7.1).

VR technology can not only stimulate the scenes in real world, but also transcend the limits of time, space, and even human's physical senses to retrieve the scenes that doesn't exist in current society or to create a new world that is fully imagined. Using VR technology, the physical space can be zoomed and transferred to represent micro- and macro-worlds, making the abstract concepts concretized. VR technology, therefore, can be applied widely in science education, for instance, learners can learn about astronomy by walking on a virtual planet (Yair, Mintz, & Litvak, 2001) or explore the structures of molecules and cells in the micro-world with VR technology (Limniou, Roberts, & Papadopoulos, 2008). VR technology can also be used while learning arts. For example, students can "go back" to the reappeared historical scenes and events via the VR technology to "visit" the original sites and observe the restored virtual antiques, through which they can learn history by a close observation.

Operational Learning

The VR technology can offer a platform for tactile learning. Using the situated learning environment created by VR, learners are allowed to operate the objects with their own hands, to observe and to experience carefully. Simultaneously, immediate feedbacks for learners' operations and behaviors are provided, helping the learners correct their wrong operations and understanding during learning. More specific, by simulating the real scenes in skill training, VR technology provides the learners opportunities to practice over and over again, facilitating the skills transfer into the real tasks, for example, driving training and medical operation training.

Compared with those training which may cost high or exist some dangers in the real world, the VR technology can provide a training platform in a more convenient and a safer way. In addition, when learning to understand some complex concepts, the learners can observe their learning outcomes and examine their hypothesis by operating or controlling the learning objects in the virtual world so as to adjust their original understanding and construct the deep comprehension. For example, the "Science Space" project developed with NASA's fund includes a virtual platform called "Newton World", which can simulate the scenes where there is no any gravity and friction. The learners can launch and catch the balls with different masses via the "virtual hands", through which they can predict, test, and elucidate the physical phenomena by real operation to learn about Newton's law of motion and the law of conservation of energy.

Social Learning

The social learning under VR environment refers to a more extensive realm in which the learners can study through the interaction and cooperation with others in the simulated social scenes. 3D virtual environment provides a multi-user virtual environment where the teachers and students are able to conduct social learning activities, highlighting its characteristic of high interaction. Therefore, VR technology is considered to be suitable for distance education as it can overpass the limits of physical distance. The students can participate in the real-time class interaction and complete the group discussions through the multi-user virtual platform. And with that, they can feel as they are in a class physically and also have some senses of belonging to the group work. VR technology can not only facilitate the cooperation among different learners in multi-user virtual platform, but can establish the connections between the real learners and the virtual avatars, promoting the information exchange and interaction in more abundant social communication ways, including verbal and non-verbal modalities.

Scientific Research

Currently, the VR technology also has great importance in the scientific research for some disciplines in addition to its application in teaching. Many academic institutions all over the world have had established the VR laboratories, especially in the science areas. The VR technology is capable to simulate various science and engineering environments conveniently, thus greatly decreasing the cost and risk of conducting experiments in real laboratories. In addition, the VR technology can stimulate or create some scenes and effects, which cannot be achieved in the real world, through which the experiment conditions can be manipulated and controlled flexibly. For example, in medical research, VR can visualize the inner organs and make it accessible for the researchers to "operate" some virtual nervous tissue (Morehead et al., 2014).

7.2 Bibliometric Analysis

7.2.1 Data and Methodology

In this study data were extracted from Thomson Reuters's Web of Science (WoS). HisCite^{TM} software was used to analyse the data retrieved from the database. Many researchers recommended WoS because it provides bibliographic data of individual articles along with information about their cited references (Matthews, Abdelrahman, Powell, & Lewis, 2016; Tseng, Chang, Tutwiler, Lin, & Barufaldi, 2013; Zhang et al., 2014). WoS was searched using the keyword search terms ("virtual reality" or "immersion" or "augmented reality" or "mixed reality" or "immersive learning environment" or "virtual embodiment" or "virtual world" or "head mount display" or "virtual environment" or "sensory immersion" or "virtual classroom" or "virtual training" or "immersive learning" or "augmented learning") and ("learning" or "education" or "training" or "simulation" or "interactive learning environment"). In Thomson Reuters's Web of Science (WoS), each article is assigned to one or more subject categories. *Education & Educational Research (139), Educational Psychology (43), Special Education, (30), and Education, Scientific Disciplines (27)* are included in *Education* subject category.

Data retrieval was conducted within WoS for the period 1995–2016 through the following steps (see Fig. 7.2). Firstly, the documents were searched using first group and second group of keywords (Step 1). Secondly, all the searched results obtained in the Step 1 were combined, and duplicates were removed (Step 2). A total of 10,235 publications were identified. Thirdly, publications were refined by subject categories in *Education* (Step 3). A total of 1228 documents were obtained. In the next step, data obtained in the Step 3 were refined by source titles (Step 4). To improve the reliability and validity of the results, the data cleaning was conducted by examining the abstracts of the records obtained (Step 5). Finally, a total of 975 publications were collected on 2016/09/27 for bibliometric analysis (Step 6). There has been an exponential increase in virtual reality publications in education over the past 20 years. The growing trend line in Fig. 7.3 shows that virtual reality has got increased attention from the researchers.

Our analysis was limited because of the choice of the language as English. This may have overlooked some of the important publications. In addition, we did not include publications referred such as proceeding papers, dissertations, editorial, book chapters, etc.

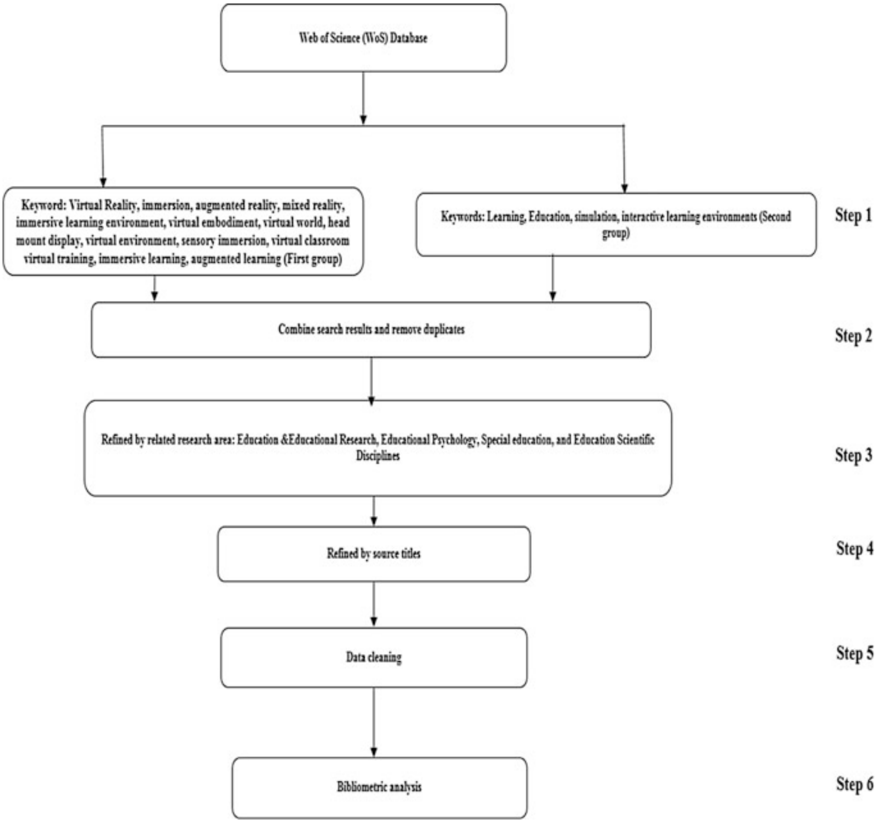

Fig. 7.2 The data collection and cleaning procedure

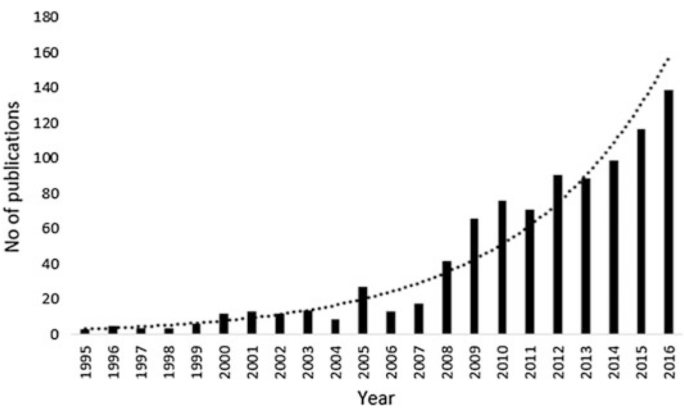

Fig. 7.3 The growth of virtual reality publications in education from 1995–2016

7.2.2 Empirical Results

7.2.2.1 Document Types and Languages

There were four document types were identified among 975 publications on virtual reality in education. The most common document type is peer-reviewed journal articles (930), accounting for 95.3% of the total. Proceeding papers were identified to account for 3.3%. The other documents were review (8) and editorial letter (4). All peer-reviewed journal articles were used for the further analysis because they are more prevalent document type and provide more information to identify research trends. As much of 99.7% of the journal articles were published in English. This result shows that English dominates the official international academic language for research in virtual reality.

7.2.2.2 Major Journals and Their Publication

Articles on virtual reality were published in wide range of 75 SCI/SSCI journals. Table 7.1 lists the top 20 most productive journals in virtual reality research in education, along with the total number of articles published, the number of LCS and GCS. The major journals for virtual reality research included *Computers & Education, Journal of Surgical Education, International Journal of Engineering Education, and Educational Technology & Society*. In *Computers & Education,* 139 articles, or 14.9% out of the 930 journal articles, were published, and received 370 LCS and 3292 GCS. The journal *Journal of Surgical Education* ranked second in terms of publication numbers, with 74 published articles and 31 LCS and 585 GCS. These results indicate that *Computers & Education* is the most outstanding journal in virtual reality research.

7.2.2.3 Most-Prolific Authors

A total of 2383 authors (co) produced just one article, accounting for approximately 89% of the total authors. Table 7.2 lists the top 10 most-prolific authors, each with no less than 5 articles. The most productive author was *Roshan Aggarwal* from Faculty of Medicine, Imperial college London, U.K, with 8 articles, 6 LCS and 168 GCS. Most of the top productive authors are from English- speaking countries. This result reveals that English-speaking countries is dominating virtual reality research field.

Table 7.1 Top 20 most productive journals based on total number of articles published

	Journal	TA	LCS	GCS
1	Computers & Education	139	370	3292
2	Journal of Surgical Education	74	31	585
3	International Journal of Engineering Education	39	18	179
4	Educational Technology & Society	38	44	406
5	Computer Applications in Engineering Education	35	33	173
6	British Journal of Educational Technology	33	110	828
7	Anatomical Sciences Education	31	84	414
8	Interactive Learning Environments	30	23	134
9	Medical Teacher	27	44	1422
10	Academic Medicine	25	13	672
11	Journal of Computer Assisted Learning	24	34	392
12	IEEE Transactions on Learning Technologies	22	12	136
13	Australasian Journal of Educational Technology	17	8	65
14	BMC Medical Education	16	0	183
15	Journal of Educational Computing Research	16	4	68
16	Journal of Science Education And Technology	16	39	235
17	Medical Education	16	79	943
18	ETR&D-Educational Technology Research And Development	14	54	408
19	Nurse Education Today	13	2	90
20	IEEE Transactions on Education	12	15	224

Note TA Total number of articles, *LCS* Local citation scores, *GCS* Global citation scores

Table 7.2 Top 10 most-prolific authors based on total number of articles published

	Author	Country	TA	LCS	GCS
1	Aggarwal R	UK	8	6	168
2	Darzi A	UK	8	13	342
3	Wilson TD	Canada	7	23	92
4	Goktas Y	Turkey	6	5	14
5	Hwang GJ	Chinese Taipei	6	7	85
6	Kneebone R	UK	6	15	388
7	Passig D	Israel	6	3	8
8	Ahmed K	UK	5	3	34
9	Bjerrum F	Denmark	5	0	16
10	Dasgupta P	UK	5	3	34

7.2.2.4 Geographic Distribution and International Collaboration

A total of 59 countries/regions contributed to virtual reality research. However, only 19 countries/regions (32.2% of the total) published more than 10 articles, and 15 countries/regions (25.4% of the total) produced only one article. USA was the most productive country with 316 articles, followed by U.K (100). Table 7.3 lists the top 10 most productive countries/regions in virtual reality research field. Among the top 10 prolific countries/regions, 4 countries are English-speaking countries and their total output accounted for 540 articles, 58.06% of the total. Interestingly, Chinese Taipei and Peoples R China are the two emerging Asian countries/regions which listed in top 10. Figure 7.4 displays the network visualization among the countries/regions for virtual reality research.

The institutional distribution of virtual reality research is also uneven geographically. A total of 930 articles were distributed over 903 institutions, however, 610 institutions, or 67.5% of the total institutions produced only one article. Table 7.4 lists the top 10 research institutions involved in virtual reality research.

7.2.2.5 Highly Cited Papers

From Table 7.5, it is clear that most of the research related to VR has been conducted in medical education. Applications of VR in school and university teaching and learning is yet still need a lot of attention from the educators and stakeholders.

7.2.2.6 Most Frequently Used Keywords

A total of 2103 keywords were extracted. This includes author keywords and keywords plus. *Keyword Plus* are the indexing keywords which are provided by WoS. Table 7.6 lists the top 10 keywords which were used frequently. The top 10

Table 7.3 Top 10 most productive countries/regions based on total number of articles published

	Country/Regions	TA	LCS	GCS
1	USA	316	469	5884
2	UK	100	131	1935
3	Chinese Taipei	94	153	938
4	Canada	70	85	643
5	Spain	64	56	584
6	Australia	54	42	563
7	Peoples R China	38	22	279
8	Netherlands	26	3	230
9	Turkey	23	20	202
10	Greece	21	29	408

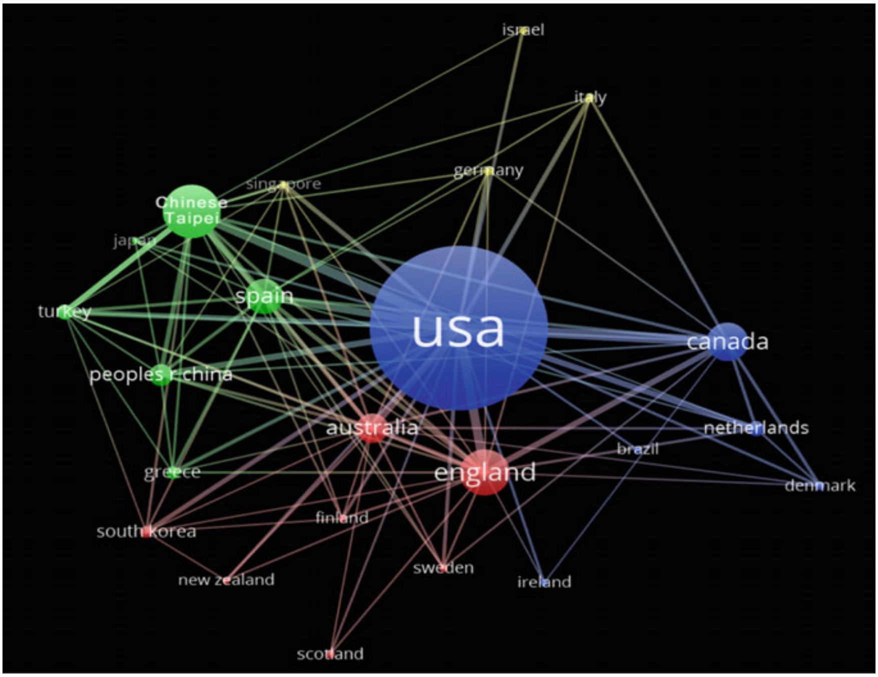

Fig. 7.4 The network of top 20 countries/regions involved in virtual reality research

Table 7.4 Top 10 productive research institutions of virtual reality research in education

	Institutions	Country/Region	TA	LCS	GCS
1	Taiwan Normal University	Chinese Taipei	22	48	227
2	Taiwan University of Science & Technology	Chinese Taipei	17	55	303
3	Central University	Chinese Taipei	16	23	139
4	Harvard University	USA	15	46	458
5	University of Toronto	Canada	14	2	107
6	Arizona State University	USA	12	14	120
7	Imperial College London	England	12	11	282
8	University of Western Ontario	Canada	12	28	136
9	University of Illinois	USA	10	7	127
10	Bar-Ilan University	Israel	9	8	26

high frequency keywords were used for 541 times, accounting for 25.7% of the total keyword frequency appearances. From Fig. 7.5, it is found that there has been wide application of virtual reality in medical education.

Table 7.5 Top 10 most cited articles

Cited references	TA
Seymour NE, 2002, ANN SURG, V236, P458, DOI 10.1097/01.SLA.0000028969.51489.B4	34
Dalgarno B, 2010, BRIT J EDUC TECHNOL, V41, P10, DOI 10.1111/j.1467-8535.2009.01038.x	33
Barab S, 2005, ETR&D-EDUC TECH RES, V53, P86, DOI 10.1007/BF02504859	31
Dunleavy M, 2009, J SCI EDUC TECHNOL, V18, P7, DOI 10.1007/s10956-008-9119-1	30
Nicholson DT, 2006, MED EDUC, V40, P1081, DOI 10.1111/j.1365-2929.2006.02611.x	29
Wu HK, 2013, COMPUT EDUC, V62, P41, DOI 10.1016/j.compedu.2012.10.024	27
Garg AX, 2002, ACAD MED, V77, pS97, DOI 10.1097/00001888-200210001-00030	26
Garg AX, 2001, LANCET, V357, P363, DOI 10.1016/S0140-6736(00)03649-7	25
Dede C, 2009, SCIENCE, V323, P66, DOI 10.1126/science.1167311	23
Hew KF, 2010, BRIT J EDUC TECHNOL, V41, P33, DOI 10.1111/j.1467-8535.2008.00900.x	23

Table 7.6 Top 10 high frequency keywords

	Keywords	TA
1	Virtual reality	171
2	Interactive learning environment	64
3	Augmented reality	60
3	Simulation	54
4	Education	36
5	Second life	28
6	Virtual worlds	28
7	Laparoscopy	27
8	Teaching/learning strategies	27
9	Medical education	26
10	Immersion	20

7.3 Discussions

7.3.1 Empirical Findings from Previous Studies

Overall, the hypothesis that VR technology promotes learning has been supported by a number of previous studies. For example, in a study about using VR in biology classes on animal cells, researchers found that students had a better understanding about the complexity of the natural world (Minogue, Jones, Broadwell, & Oppewall, 2006). In another study on learning molecular chemistry, VR technology with haptics feedback contributed to the understanding of concepts, and made the learning process more interesting and interactive (Sato, Liu, Murayama, Akahane, & Isshiki, 2008).

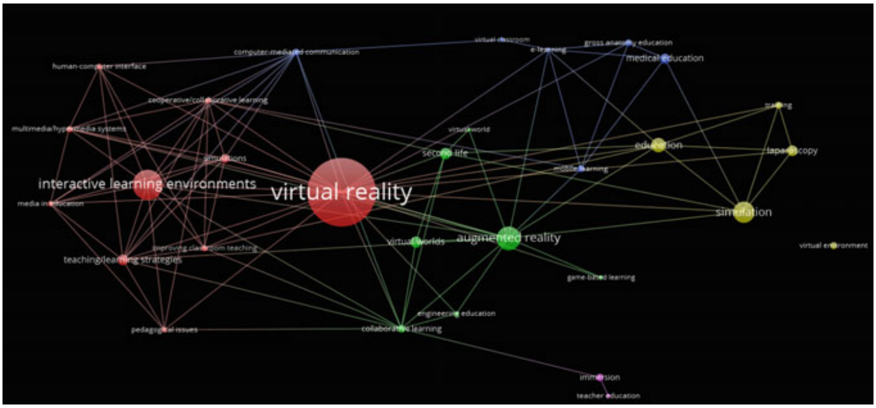

Fig. 7.5 Network visualization of 30 keywords which meet the threshold of occurrence at least 10 times

The positive effects of VR technology on learning were also found in some studies with 3D models, which were considered to be a normal form for VR technology. Nicholson et al. (2006) conducted an experiment on the effects of computer-generated 3D anatomical models on learning, and found a positive relationship between the computer-generated 3D models they used and the scores of students (Nicholson, Chalk, Funnell, & Daniel, 2006). Similar findings were also indicated by another study in which researchers used Construct3D to help students learn mathematics and geometry, and found that the knowledge presented with Construct3D was easier to learn and facilitated the learning of geometric constructions (Kaufmann, Schmalstieg, & Wagner, 2000).

Some studies based on Second Life, which is a popular VR platform in education, also revealed some positive effect on learning. The virtual campus based on Second Life was found advantageous to improving user impressions concerning presence, awareness, communication, and comfort with the virtual environment (De Lucia, Francese, Passero, & Tortora, 2009). Another study carried out over a year and half observing several groups of students found that the students who learned electronic related subjects through mixed lessons combining traditional on-site lessons with virtual lessons on Second Life platform had higher motivations for learning and attending learning activities (Sierra, Gutiérrez, & Garzón-Castro, 2012).

Some studies on collaborate learning based on VR technology were also proved positive in promoting learning, because students were able to discuss with their classmates, share their findings, and demonstrate the operations of systems to their classmates and teachers (Chen, Yang, Shen, & Jeng, 2007). When it comes to skills training, VR technology also plays an important role. In the training of assembling, VR technology was found to be better than traditional 2D engineering drawing lessons (Boud et al., 1999). One of the main reasons for this was that assembly not only had a requirement for learning sequence, but also for motor behavior. VR participants were able to investigate assembly sequences through a number of VR conditions. However, Boud et al. (1999) also highlighted that one of the main problems of VR technology is the lack of haptic feedback, which plays an important role when manipulating objects. This problem was also found when researchers compared VR technology and AR technology for training laparoscopic skills (Botden, Buzink, Schijven, & Jakimowicz, 2007).

Although many researchers put their attention on the advantages and potential benefits of the use of VR technology in the field of education, only a few of them came up with powerful proof to support their opinions with empirical experiments and quantitative data (Hew & Cheung, 2010). Some studies even showed that there were no significant differences on learning outcomes between students who learned with VR technology and students who learned in a traditional way. Merwin and Wickens (1991) compared scientific data visualization performance with 2D plan and 3D renderings, and found that 3D perspective supported short term performance but had no benefit for longer term retention. Minogue et al. (2006) failed to find any positive cognitive impacts when using VR technology to study animal cells, which however may have been due to the inaccuracy of assessment by paper and pencil. Similar results were found in Holmes's study (2007) in which a post hoc Tukey test failed to find any significant difference between three groups of learners in terms of their test scores with regard to the learning of ecological concepts. Some researchers even suggested that the use of VR technology in education might lead to lower learning outcomes. Aretz (1991) divided learners into two groups and required them to perform a helicopter flight simulation in which they navigated through a virtual world of geometric objects. One group used a track-up map that always presented their navigation information in the same orientation in their forward field-of-view while the other group used a fixed north-up map. After the navigation, both groups were asked to draw a map of the environment through which they had traveled, and it was found that the group using the fixed map showed a better retention of the position of the geographical features. Some researchers also pointed out a weakness for Second Life in that students tend to get distracted by the computer as it gives them access not only to the learning environment of Second Life but to all the social networks and the Internet in general (Sierra et al., 2012).

To sum up, although there are some studies that failed to find the promising effects and even indicated some disadvantages of VR technology in learning, the characters and advantages of VR technology has been accepted by the mainstream of researchers and practitioners, the majority of studies indicating that using VR technology might make a great difference on learning, resulting in positive effects. Nevertheless, the current studies mostly used observations, questionnaires, self-reports, and other simple methods to get the findings, thereby lacking experimental, quantitate supports. The effects of VR technology on learning needs to be repeatedly tested and confirmed by more empirical studies. It is hard to have a simple and standardized answer for the question of whether VR technology definitely contributes to learning, because it may be influenced by complex factors such as the setting, learning contents, and manipulating disparities, which also may be the reasons why the conclusions of some current researches are contradictory.

7.3.2 Challenges of VR Application in Education and Future Directions

VR technology is promising in education for it meets the principles of various pedagogical theories and methods. In recent years, some relevant research supported that VR technology can function effectively in teaching and learning. However, there are lots of challenges that VR technology has to face when applied in education, including the technology, its application in teaching, and the learners' experience (see Table 7.7).

Table 7.7 Ten challenges faced by VR technology

Categories	Challenges	Profiles
Technology	1. Controlling device cost and improving portability	To develop more portable and cheap devices and connect VR devices with modern communication terminals like smart phones, which can be applied in mobile learning
	2. The improvement of environmental simulations	To improve the product's accuracy, reaction speed and presenting various feedback information including the sense of touch, force and smell, which can strengthen the sense of immersion
	3. The improvement of interaction experience	To improve the experience between humans, devices and environments and develop the systemic social tools which make it easy to communicate in real-time, boosting cooperation among users
Application in teaching	4. Certify system content and teaching strategy	To certify the teaching objects that fits the VR technology, design adequate system contents and explore the effective teaching strategies and principles in VR learning environment
	5. The avoidance of cognitive overload	Cognitive overload should be fully considered when constructing a virtual learning environment. Both the scene design and the organization of learning materials will avoid causing overload in cognition
	6. The supervision and evaluation of learning effects	To stress on the tracking, supervision and evaluation of the learning behaviors in the VR learning environment. Furthermore, more strict empirical researches should be conducted focusing on the teaching effects of this technology

(continued)

Table 7.7 (continued)

Categories	Challenges	Profiles
Learners' experience	7. The reduction of difficulty in using technology	To provide relevant trainings for teachers and students about technology use and operation. Also, the expansibility of products should be improved and the users are allowed to edit and regulate the content by themselves
	8. Adapting to identity transformation and promoting identity	To help students adapt to the identity transfer in the VR environment better and to further motivate the learners' interests in participating in learning activities through improving the identity of virtual avatars
	9. The protection of the privacy and data of users	In the open VR platforms, the protection and security of personal information matters a lot. The industrial standards about product development and opening should be regulated
Comprehension	10. The integration of technology and the applicable smart learning environment	To strengthen the compatibility of VR and other education technologies, VR learning environments and the real learning environments. Also, to flexibly use various technologies in teaching to create the optimized smart learning environment based on teaching goals

7.3.2.1 From the Perspective of Product Technologies

Control the Devices' Cost and Strengthen Compatibility: Generally speaking, the cost of VR devices is relatively high at present, especially those devices which are fully-immersing through helmets. The output devices with high accuracy like the VR helmets are too heavy to carry for a long time. The cost of this technology has been constantly decreasing with the development of more and more VR products. Nevertheless, it is necessary to develop more portable and cheaper devices in order to widely spread and apply VR technology in education. Furthermore, VR devices should be connected with modern communication terminals including smart phones and pads to apply into fields like mobile learning.

Improve Environment Simulations: The highly immersive VR technology has a strict requirement for the simulations of its learning environment. Only by improving the VR simulations both in scene setting and operating experience can the students achieve deep understanding under the natural sematic state in the near-real learning environment. Some users will feel dizzy when they are using VR products currently, especially after a long-time use, mainly due to incompatibility between the VR visual stimulus and the self-sense stimulus of the users. Therefore, it is needed to further improve the accuracy and reaction speed of the VR products and try to reduce the delay of visual stimulus. Besides, most of the current VR systems are still only focusing on offering visual and auditory information. But it is only by presenting various feedback including the sense of touch, force and smell can the students generate the sense of immersion to the different aspects of the learning objects, improving the comprehensive simulations of VR environments.

Improve the Interaction Experience: Although interaction is another eminent feature of VR technology, the interaction experience of the current VR learning system still needs to be improved. On the one hand, the interaction experience between the users and the systems needs to be enhanced from the perspective of technologies, allowing the users to manipulate and control the VR environment and the objects in it in a more natural way. On the other hand, the tools for social communication between individuals in VR learning systems have a limited range, with the traditional verbal information as the major form of interaction. Although some non-verbal information can be presented through body movements and facial expressions of virtual avatars, the effectiveness of these communication cannot be compared with social interaction in a real environment. Thus, besides improving the more natural interaction between humans and devices and environments, VR technology needs to be expanded with more social tools for convenient real-time communication, supporting the cooperation among various users.

7.3.2.2 From the Perspective of Teaching Application

Certify System Content and Teaching Strategy: The first issue that needs to be considered in teaching application is what to be taught and how to teach it with VR technology. Though VR technology has the potential of being applied in numerous disciplines, this technology's advantages can only be fully present and the learning effects can only be optimized by specifying the suitable application scale and teaching objects. This makes clear the principles of presenting and constructing VR environments and developing and designing more abundant VR system content matching the teaching requirement. However, there is still a lack of systematic and mature methodology in rendering VR technology to teach. The effective teaching contents and strategies need to be further explored in the VR environment to find out how to present the knowledge from textbooks in the environment, how the students study by themselves in the VR environment, and how the teachers guide the students in the VR environment.

Avoid Cognition Overload: The amount of multi-channel information carried in the VR environment will deliver pluralistic information to the users, which causes an overload in cognition and this affects learning outcomes if designed inappropriately. The students may be distracted by the numerous functions and simulated scenes of the VR world, disturbing their attention from the objective learning contents. The students' sense of presence can be strengthened by the pluralistic information, but the delivery of information can also be repetitive and redundant, causing a waste of cognition resources. The construction of VR learning environment is different from other stimulation environments created for entertainment and games, because the ultimate aim of a VR learning environment is to deliver knowledge and to make students devote their limited recognition resources into the activities that have direct connections with the learning objects. Therefore, the element of cognition load should be taken seriously in the construction of VR learning environments. The design of all scenes and the presence and organization of learning materials should follow the cognition process of the students, avoiding cognition overload in learning. For example, the influence of VR to the cognition process and learning outcomes, such as the number and layout of the objects in the environment, the organization and presence of pluralistic media (such as sound, words, images, animations), and the level of knowledge of the learners should be considered.

Supervise and Evaluate the Learning Effects: When applied in actuality, the VR helmet will create a fully-immersive learning environment in which the teachers cannot distinguish students' learning states according to the traditional behaviors and reactions (like the expressions of distraction and confusion), making it difficult for teachers to control the teaching process instantly. Thus, more auxiliary technologies should be involved in the VR system to help track, record and evaluate the learning behaviors better, providing the feedbacks of learning effects for the students and teachers. As for teaching research, it is a necessity to conduct experiments with strict control and select the available effect indexes. This will contribute to implementing empirical researches focusing on teaching effects in VR environment with different learning objects and teaching methods. Furthermore, it is necessary to conduct long-term longitudinal studies to examine the long-term effect of learning outcomes in VR environments and explore whether it is possible to transfer what students learn into the tasks in real environment.

7.3.2.3 From the Perspective of Dimension of Learners' Experience

Reduce the Difficulty of Using Technology: As it is a new and complicated technology, a VR system requires users to adapt to the particular ways of operation, which may be difficult. To ensure using the VR technology fluently in classes, the teachers should be trained about the technology to guide the students and solve the problems of using it. Meanwhile, the students should also receive some relevant training courses and practices before using the VR system to guarantee fluent use and reduce the overload brought by the technology itself. In addition, considering the poor expansiveness of most current VR products, users cannot edit and regulate the contents according to their own needs, causing some inconvenience in practical application.

Adapt to Identity Transformation and Promote Identity: The virtual identity created by the students in a VR environment may have differences with the real one, which will decrease the students' sense of identity. The identity will affect the students' learning motivation in social environment. VR is a social stimulation environment with a high interaction, especially in the multi-user virtual platforms, in which the students will not finish their learning tasks and interact with others if they lack the sense of identity. Therefore, in character design for virtual environments, it is necessary to consider how to help students adapt to the identification transformation and further stimulate their interests in participating in virtual learning activities through promoting identity. In the future, researchers can study the principles for the learners to use virtual avatars and the ways the avatars affect the learning effects. For example, it can be studied whether students prefer to use avatars which are close to the real identity or close to the ideal self. Moreover, it can be researched how the characteristics of virtual characters affect the social interaction between them and the students, and how the students perceive the information delivered from avatars.

Protection for the Privacy and Data of Users: The issue of personal privacy is taken seriously by the educators of K-12 when applying VR technology (Dawley, 2009). The protection of the user's privacy, especially the privacy of the under-aged, needs thorough attention in VR platforms that are widely open. Currently, there is no adequate industrial standards for the development and opening of VR products and the relevant education products.

Taking the three dimensions into account, the last challenge of applying VR technology in education is the technology integration of it, including promoting the compatibility between VR technology and other education technologies and between the VR environment and the actual learning environment. "VR plus education" is a kind of education tool rather than a new education method, which contributes to the traditional teaching mode instead of substituting traditional classes. The current VR products lack the standards for open design, which will cause some problems for the users who want to integrate other education technologies and teaching resources. It is worth studying how to combine VR technology and other education technologies, how to connect perfectly the VR environment and the actual learning environment, and how to make VR contents cover different disciplines. The aim of discussing and researching VR technology is to better meet the teaching requirements and create an optimized smart learning environment based on specific learning goals, where all kinds of technologies can be flexibly exploited.

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Part II
Case Studies of Immersive Learning

Chapter 8
Virtual Reality as an Immersive Medium for Authentic Simulations

The Case of EcoMUVE

Chris Dede, Tina A. Grotzer, Amy Kamarainen and Shari J. Metcalf

Abstract This chapter describes a design strategy for blending virtual reality (VR) with an immersive multi-user virtual environment (MUVE) curriculum developed by the EcoLearn design team at Harvard University for middle school students to learn ecosystems science. The EcoMUVE Pond middle grades curriculum focuses on the potential of immersive authentic simulations for teaching ecosystems science concepts, scientific inquiry (collaborative and individual), and complex causality. The curriculum is inquiry-based; students investigate research questions by exploring the virtual ecosystem and collecting data from a variety of sources over time, assuming roles as ecosystems scientists. The implications of blending in VR for EcoMUVE's technical characteristics, user-interface, learning objectives, and classroom implementation are discussed. Then, research questions for comparisons between the VR version and the "Classic" version are described. The chapter concludes with generalizable design heuristics for blending MUVE-based curricula with head-mounted display immersion.

Keywords Immersive authentic simulation · Ecosystems science
Scientific inquiry · Complex causality · Multi-user virtual environment
Virtual reality

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8.1 Introduction

We live at a time of rapid advances in both the capabilities and the cost of virtual reality (VR), multi-user virtual environments (MUVEs), and various forms of mixed reality (e.g., augmented reality (AR), tangible interfaces). These new media potentially offer extraordinary opportunities for enhancing motivation and learning across a range of subject areas, student developmental levels, and educational settings.

An attribute that distinguishes immersive from real world learning and potentially makes it more powerful, is the ability to create interactions and activities in mediated experience that are not possible in the real world. These include, for example, teleporting within a virtual environment, enabling a distant person to see a real-time image of your local environment, or interacting with a (simulated) chemical spill in a busy public setting. However, while immersion is intrinsically helpful for motivation and learning in some ways, it is not necessarily useful in others. For example, in mastering complex knowledge and sophisticated skills, students learn well in a Plan, Act, Reflect cycle (Lewin, 1946; Kieran & Saldanha, 2008): first they prepare for an experience that involves doing something they want to master; then they attempt that performance; and finally they assess what went well, what did not, why, and what they need to learn in order to execute a more successful repetition of the cycle. Immersion is helpful for the Act part of the cycle but, unless used carefully, can interfere with the Plan and the Reflect parts of the cycle. This—and numerous other factors—make effective instructional design for immersive learning complex.

To maximize the power of immersive learning, it's important not to present isolated moments in which VR, MUVEs, and AR merely provide short-term engagement or fragmentary insight. Instead, extended experiences that immerse students in rich contexts with strong narratives, authentic practices, and links to real world outcomes are what truly unleash the transformational power of immersion. For example, while showing a 3-D model of a human heart illustrating blood flow is useful, immersing students in a virtual setting where they are applying knowledge of the heart to save the lives of computer-based agents is much more motivating, as well as effective in fostering a wide range of complex knowledge and sophisticated skills.

That said, as discussed in Richards' chapter, because of issues like simulator sickness, isolation from the real world, and technical limits on shared VR experiences, implementing an extended learning experience in VR only is challenging and often sub-optimal. This chapter discusses ways to blend VR with MUVE/monitor-based interfaces in ways that create a transmedia narrative (Warren, Wakefield, & Mills, 2013), in which each modality contributes its own rich capabilities to overall learning. To derive and illustrate generic design heuristics for VR as a complement to other forms of immersion, we present a case study of EcoMUVE, a MUVE-based curriculum for ecosystems science education, describing the alterations needed to produce a version of this curriculum that blends in VR.

8.2 EcoMUVE: Immersive Authentic Simulations for Learning Ecosystems Science

EcoLearn is an educational research group at the Harvard Graduate School of Education that explores the use of emerging immersive technologies to support learning about the process of scientific inquiry and the complex causal dynamics of ecosystems. Thus far, EcoLearn has developed a completed curriculum, EcoMUVE, and is currently designing and studying EcoXPT, an extension of EcoMUVE that adds experimentation that is authentic to ecosystems science, and EcoMOD, a third grade curriculum that infuses computational modeling into ecosystems science education. Details about EcoLearn overall and about our completed augmented reality curriculum (EcoMOBILE) that complements our MUVEs are available at http://ecolearn.gse.harvard.edu.

The EcoMUVE middle grades curriculum focuses on the potential of immersive authentic simulations for teaching ecosystems science concepts, scientific inquiry (collaborative and individual), and complex causality (Grotzer, Kamarainen, Tutwiler, Metcalf, & Dede, 2013; Metcalf, Kamarainen, Tutwiler, Grotzer, & Dede, 2011). The curriculum has two MUVE-based modules, which center on pond and forest virtual ecosystems. Each module consists of ten 45-min lessons and represents an ecological scenario involving complex causality. The curriculum is inquiry-based; students investigate research questions by exploring the virtual ecosystem and collecting data from a variety of sources over time, assuming roles as ecosystems scientists (Fig. 8.1).

Overall, EcoMUVE enables internship-like experiences in immersive simulated ecosystems that support authentic scientific practices, including collaborative inquiry. This chapter discusses the advantages and potential problems of complementing this MUVE-based learning experience with VR. The analysis sketches possible modifications involved in reconceptualizing the curriculum's technical characteristics, user interface, learning experiences, and classroom implementation for this type of blended immersion. (This redesign description focuses on the EcoMUVE Pond curricular module; the Forest module is similar in its technical aspects, curricular approach, and the types of redesign possible.) Then, research questions for comparisons between the VR version and the "Classic" version are described. The chapter concludes with generalizable design heuristics for blending MUVE-based curricula with head-mounted display (HMD) immersion.

Fig. 8.1 A student uses an avatar to explore a virtual ecosystem

8.2.1 The Learning Objectives of EcoMUVE Pond

EcoMUVE Pond represents a pond and its surroundings, including a nearby golf course and housing development. Students visit the pond over a number of virtual days, using their avatars to explore, see realistic organisms in their natural habitats, chat with other members of their research team, and collect water, weather, and population data. This monitor/avatar-based immersion can occur from either a first-person or third-person perspective.

During a virtual summer, changes occur within the pond. These changes are subtle, but detectable both visually and through measurements of water variables. Eventually, an easily discernable "event" occurs—the larger fish in the pond die overnight. Known as a fishkill, it may be viewed as part of a larger process in play or as an event that grabs one's attention and requires explanation.

In most problem-based scenarios, students are given the problem to solve. However, in EcoMUVE they need to discern it. This design feature was included to help students learn the importance of focusing on processes/change over time. Over the course of six virtual weeks, students may notice the subtle visual changes as the water clarity shifts and fish swim closer to the surface. Eventually the fishkill captures students' attention.

EcoMUVE Pond simulates an extreme eutrophication scenario in which the proximal cause of the fishkill is low dissolved oxygen concentrations in the pond during a particularly warm and windless night, but the ultimate cause is the process of eutrophication driven by excessive fertilizer runoff followed by algae growth and decomposition. As they examine the virtual world, students learn about processes that lead to an increase (e.g. photosynthesis and mixing) or decrease (respiration (in particular bacterial respiration) and warming temperatures) in dissolved oxygen concentrations in a pond. To fully understand the fishkill, students must also recognize distant drivers of change, like fertilizer that was applied in the watershed and ran off into the pond during a recent storm.

The following affordances for recognizing change over time and process-oriented versus event-based causality are built into EcoMUVE. A time-traveling calendar tool allows students to go back and forth in time to see the subtle changes that they missed. They may talk to residents or collect data and clues. Data they've collected is stored in a table so that they can analyze temporal trends using a built-in graphing function. They can use digital tools that support understanding the flows of matter and of energy through the ecosystem.

The curriculum supports students' learning about typical ranges for water quality measurements, and helps students see how ecological processes and interactions result in variation in the measurements over time. Students conclude the unit by constructing concept maps, which represent their understanding of the ecosystem components related to the fishkill and are asked to support the relationships they've identified with evidence they've collected.

Our research measures include students' motivation to do science and feelings of self-efficacy about their abilities as scientists, students' understanding ecosystems science content and practices, students' abilities to perform individual and collaborative scientific inquiry, and students' understanding of complex causality (Chen, Metcalf, Tutwiler, 2014; Grotzer, Kamarainen, Tutwiler, Metcalf, & Dede, 2013; Kamarainen, Metcalf, Grotzer, & Dede 2015; Metcalf et al., 2014). We also have studied teachers' perceptions of the practicality and effectiveness of the EcoMUVE curriculum (Metcalf et al., 2016). We have found significant gains in all the factors listed above. (For reasons of space, the detailed results of the numerous studies we have conducted are referenced in our citations rather than summarized here.)

8.2.2 Blending VR into Features of the MUVE-Based Pond Curriculum

Moving through the Pond virtual environment offers an opportunity to realize its features (Fig. 8.2). Avatars can walk uphill to the housing development and down along a drainage ditch where water is flowing into the pond; VR potentially provides a way to reinforce students' perceptions of the topography, which is very important in understanding the dynamics of a watershed.

The map icon displayed in Fig. 8.2's upper-right-hand corner is helpful in navigating through the overall environment. The various toolbars provide options for collecting data and moving through various modalities in the world. Having so many interface icons could be difficult to view in VR and would also likely undercut a sense of presence; a VR interface that, as desired, reveals and conceals these activity options would be necessary.

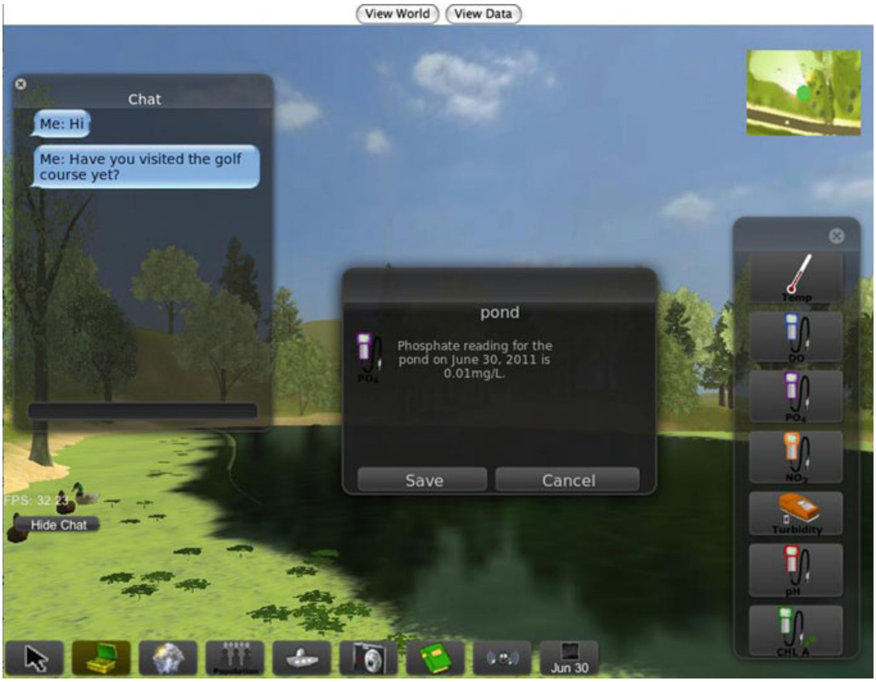

Fig. 8.2 Students can collect water, weather, and population data, as well as chat with members of their research team

Virtual agents (for instance, a park ranger, a local dog walker, and a landscaper) offer pieces of information (Fig. 8.3). Physical artifacts, such as a bag of fertilizer, also provide valuable data.

The interface for providing substantial amounts of information—and for displaying the chat shown in Fig. 8.2—is based on large dialogue boxes, which in VR would be distracting and possibly difficult to read. Finding ways in VR to communicate this information requires alternative interface modalities, such as audio communication, as well as simultaneous storage of complex information for later perusal. In our EcoXPT extension of EcoMUVE, for example, we use a team-notebook that enables easily sharing information about the pond with related comments. Gardner's chapter provides additional illustrations of immersive communication tools, and Kraemer's chapter discusses the importance of collaboration in learning.

Linked visual representations reinforce abstract concepts (Kamarainen, Metcalf, Grotzer, & Dede, 2015); students can measure pond turbidity and link the measurements to their experiences by seeing how murky the water looks on different days (Fig. 8.4). Using a "submarine" tool, they can also shrink to microscope size to see organisms within the pond that are invisible at normal scale (Fig. 8.5). Slater's chapter discusses the value this type of virtual embodiment provides.

Fig. 8.3 Talking to Manny and observing the bags of fertilizer

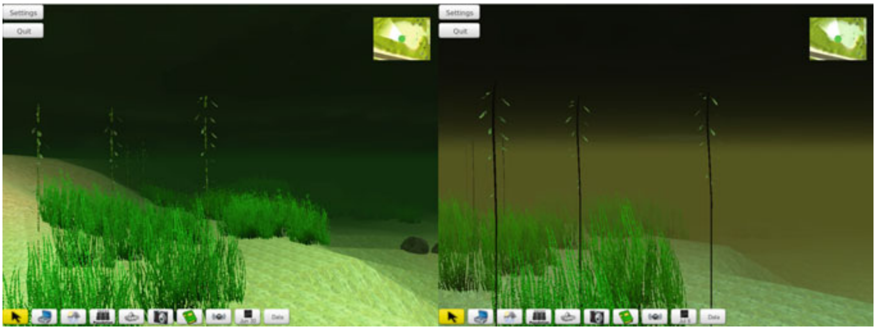

Fig. 8.4 Visual changes in turbidity of the pond on different days

The submarine tool is implemented so that students can travel directly up and down in the pond, to observe organisms at various depths, and can turn in a circle at any vantage point—but cannot navigate immersively into the water. While this experience is currently implemented in 2-D (looking through a submarine window),

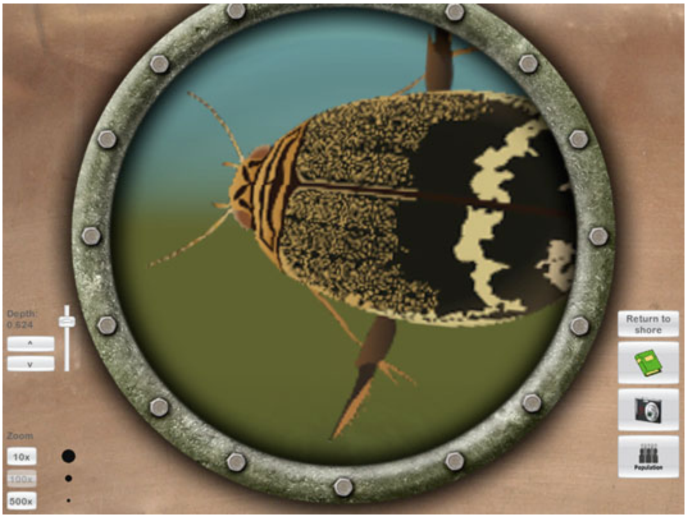

Fig. 8.5 The submarine tool allows students to see and identify microscopic organisms

Measurement	June 30	July 6	July 10	July 16	July 22	July 25	July 28	August 15
Water Temperature (°C)	22	19	21.5	24.5	26.5	27.5	25.5	25
Dissolved oxygen (mg/L)	8.4	9.5	9.4	10.2	5.4	4.1	7.3	8.4
Phosphates (mg/L)	0.01	0.1	0.03	0	0.015	0.018	0.035	0.025
Nitrates (mg/L)	0.15	0.56	0.33	0.21	0.11	0.2	0.3	0.28
Turbidity (NTU)	5	25	35	65	25	10	15	30
pH	7.2	6.7	8	8.4	7.3	7.2	7.6	8.2
Air temperature (°C)	25.5	20	24.5	26.5	31	34	27.5	26.5
Wind speed (m/s)	1.5	4.5	3	2	1.5	0	3.5	2
Cloud cover (%)	40	100	0	20	100	100	20	20
Bacteria population (cells/ml)	5000	5000	5000	7000	12000	40000	33000	14000
Bluegill population	189	163	152	123	114	109	0	
Bluegreen algae population (cells/ml)	800	900	1300	1600	1000	500	400	400
Green algae population (cells/ml)	1000	2000	5500	7000	4000	1500	1000	2000
Heron population	2	2	2	2	2	2	5	7
Largemouth bass population	38	37	35	35	33	32	0	
Minnow population	356	320	299	278	250	237	233	446

Fig. 8.6 The data table guides students in what to measure over time

reimplementing in VR would reduce the number of times students switch interface-modalities.

Students measure environmental variables to collaboratively complete a Data Table that numerically reveals changes over time (Fig. 8.6); they can then display longitudinal graphs showing correlations among the data they have collected (Fig. 8.7). These are easier to view and to manipulate through a monitor-based interface, and VR offers no interpretive advantage.

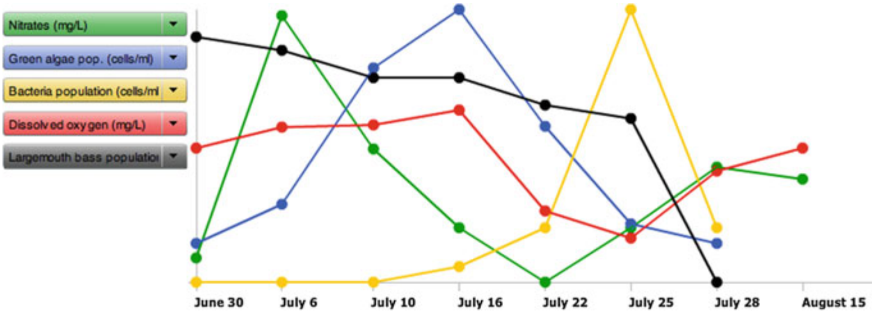

Fig. 8.7 Graphs display correlations in how variables change over time

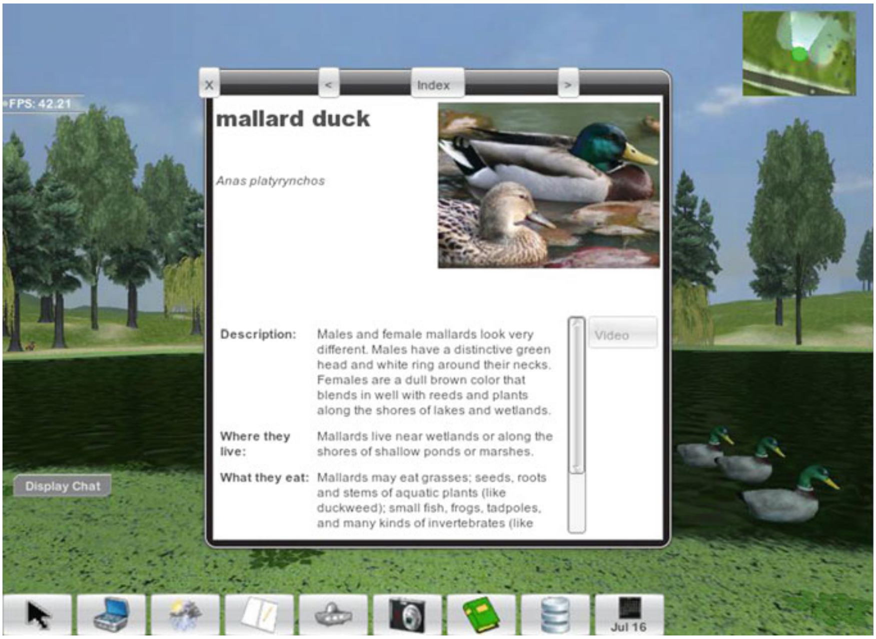

Fig. 8.8 The field guide provides information on organisms students find

Based on entries in the Field Guide (Fig. 8.8) from organisms they have found, students can also construct a Food Web to show the flow of energy through the ecosystem (Fig. 8.9). In addition, they can view an Atom Tracker feature to show the flow of matter over time (Fig. 8.10). Both of these dynamics, not apparent through sensory information, are important in understanding the causality of ecosystems.

The Food Web tool is implemented outside of the virtual ecosystem, and is easier to use without VR, since no immersion is involved. Both the Field Guide and

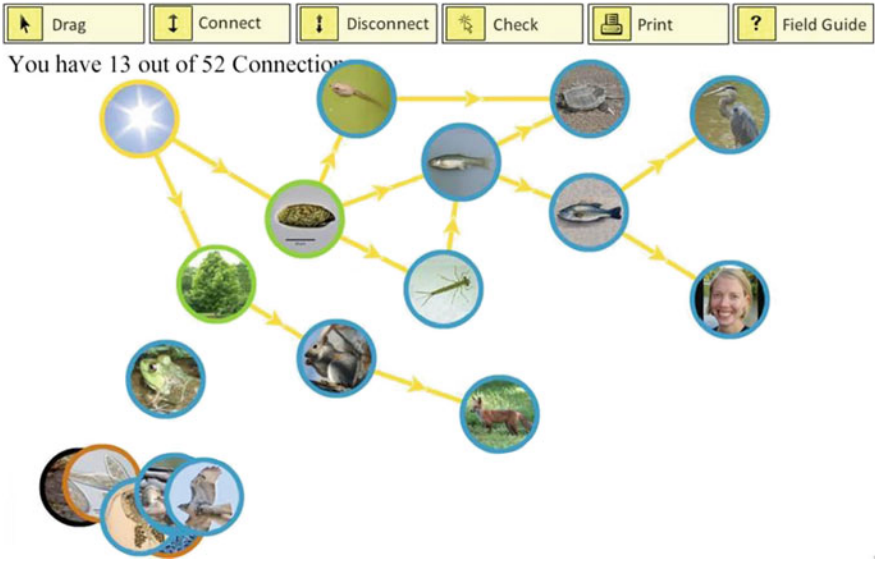

Fig. 8.9 Students develop a food web for the pond ecosystem to show energy flows

the Atom Tracker display complex visual and alphanumeric information not easily processed at the current image resolutions possible in VR. Since leaving VR would disrupt the flow of activity and interpretation, the gist of this information can be communicated via audio descriptions, as well as simultaneous storage of these artifacts for later viewing in detail.

Students can use six interactive learning quests (Fig. 8.11), implemented outside the virtual world, to learn more about content related to pond dynamics (Chlorophyll a, Turbidity, pH, Nitrates and Phosphates, Dissolved Oxygen, and Bacteria). There is no educational advantage from monitor-based viewing to porting these to VR.

The Pond curriculum uses a "jigsaw" pedagogy; students work in teams of four (Table 8.1) and are given roles (e.g., botanist, microscopic specialist).

Each student then performs data collection specific to his or her role in the virtual pond ecosystem, sharing this data with teammates within the immersive interface via tables and graphs. (As discussed later, collaboration in world is possible in the VR version only if it is implemented via a server.) Each team works collaboratively to analyze the combined data and understand the ecosystem interrelationships. The curriculum culminates in each team creating an evidence-based concept map representing their understanding of the causal relationships in ecosystem and presenting it to the class (Fig. 8.12).

A video showing the "look and feel" of EcoMUVE is available at http://ecolearn.gse.harvard.edu/ecoMUVE/video.php.

Overall, the curriculum offers complementary opportunities for observational field-work and interpretive lab-work. This is an example of the rich activities

Fig. 8.10 An oxygen molecule describes a stage of its journey through the ecosystem

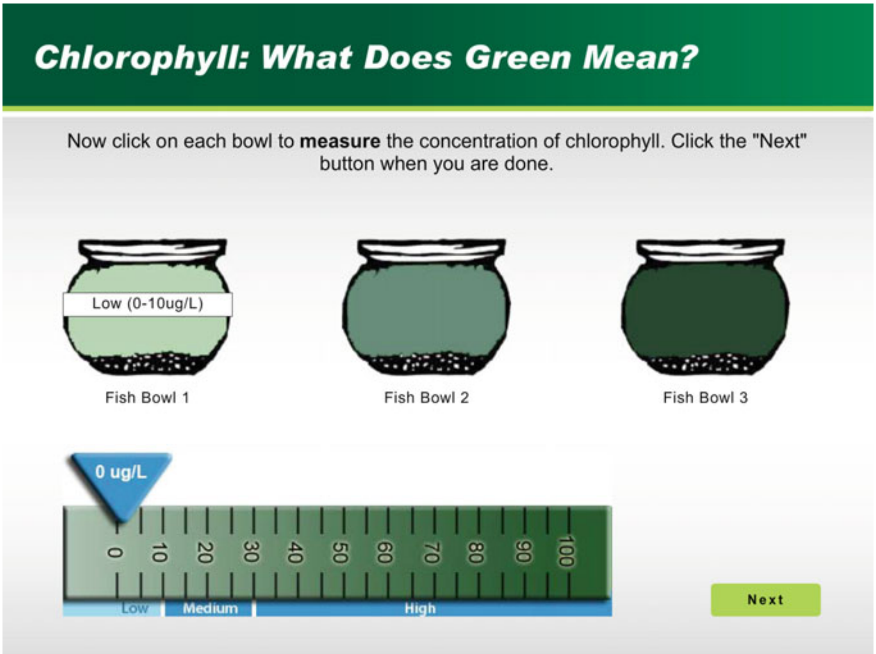

Fig. 8.11 Screenshot from interactive learning quest for chlorophyll

Table 8.1 Students work in teams of four with complementary data collection roles

Naturalist	Microscopic specialist	Water chemist	Private investigator
Collect population data for the pond organisms on different days: largemouth bass, bluegill, minnows, and great blue herons	Collect population data for the microscopic organisms in the pond on different days: bacteria, bluegreen algae, and green algae	Collect water measurement data on different days: water temperature, dissolved oxygen, phosphates, nitrates, turbidity, pH, and Chlorophyll a	Observe the weather on different days; collect measurements of air temperature, cloud cover, and wind speed
Use the field guide to learn about the different fish species	Use the field guide to learn about the bluegreen algae, green algae and bacteria	Review your notes from the learning quests on chlorophyll, turbidity, pH, nitrates and phosphates, and dissolved oxygen	Talk to the landscaper, golf course manager, utility worker, ranger, birdwatcher, and other people near the pond
Use the graphs to look at the fish population data. How did each population change over time? Write down your ideas about why	Use the graphs to look at the algae population data. How did it change over time. Write down your ideas about why	Use the graphs to look at each of the measurements you collected. Describe in words how each measurement changes over time	Write down observations about the pond and surrounding area. Take notes about changes you observed over time
Use the graphs to look at the heron population data. How it change over time? Write down your ideas about why	Use the graphs to look at the bacteria population data. How did it change over time. Write down your ideas about why	Write down any ideas about why the water measurements might have changed, and how the changes might relate to other things happening around the pond	Use the graphs to look at weather data. How do air temperature, cloud cover, and wind speed change over time? Write down your ideas about why
Use the atom tracker to find out what happens to the oxygen atom, the carbon atom, and the phosphorus atom on different days			
Work together to create a concept map that represents the causal relationships of the pond ecosystem based on the whole team's observations			

Klopfer describes in his chapter. As a general design principle, VR is not necessary and often cumbersome for data-based lab-work and related scientific briefings (e.g., the Field Guide, Atom Tracker, Learning Quests, and Food Web and Concept Mapping tools), but can selectively enhance the observational field-work. Creating a link from what is collected in the field (immersed in the virtual world) to what is interpretable in the lab (face-to-face interactions using monitor-based resources) is important. In-world, students could use a Notebook tool to store observations (e.g.,

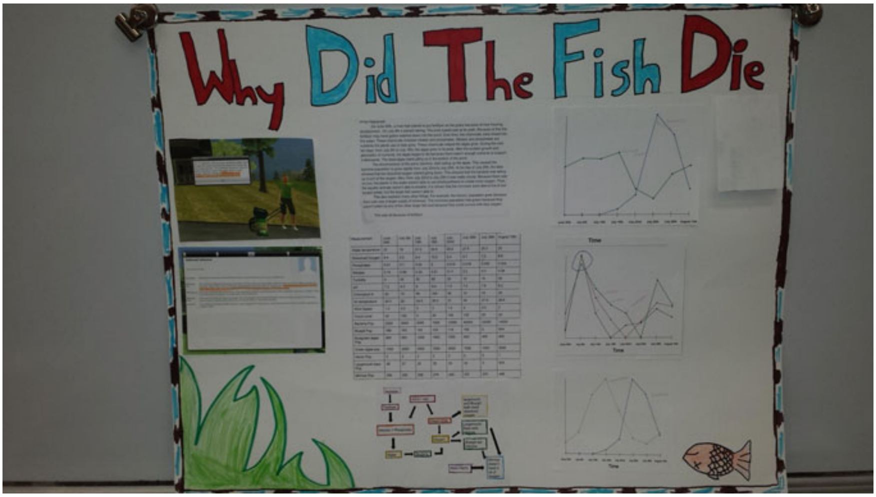

Fig. 8.12 Team's explanation including data and concept map

images captured of phenomena; interactions with in-world characters; information from the data-table, Atom Tracker, and Field Guide) for later interpretation.

A teachers' guide is available for helping students learn via the EcoMUVE curriculum, including an overview of the ecosystems content, causal understanding goals, pedagogical methods, technical information and a detailed day-by-day lesson plan (Metcalf, Kamarainen, Tutwiler, Grotzer, & Dede, 2013). This would be modified to highlight the types of learning opportunities VR makes uniquely available.

8.2.3 Technical Characteristics for EcoMUVE Pond

EcoMUVE has two versions: server-based and stand-alone. The stand-alone version lacks opportunities for team members to interact and does not collect logfiles, but is useful in school settings where the EcoLearn team does not wish to provide server access (which is a resource limited to our research sites). Student teams using the server-based version can text-chat in-world and can easily share data among teammates. However, this is not possible in the stand-alone version, in which students must rely solely on classroom interactions and use more cumbersome means to combine individually collected resources. The stand-alone version and the server version have recently been redone in Unity 5, which supports advanced features useful for research, such as HeatMaps that visually display the amount of time students are spending in various locations.

Some of the digital tools and supports (e.g., Food Web, Learning Quests) are implemented in Flash and are accessed independently of EcoMUVE through a browser interface. A concept mapping tool that enables preparing these representations digitally was developed for EcoXPT and could be added to EcoMUVE; this allows students to easily link digital resources like data tables, graphs, and screenshots. (The ability to take "screenshots" in VR would be useful for this purpose.) Also, a tool is almost finished that will enable visualizing activity patterns in the logfiles of students' behaviors in the virtual world and in the virtual reality; this will be helpful for students, teachers, and researchers (Dede, 2013). As discussed in Shute's chapter, these activities can be automatically scored in real-time to provide diagnostic feedback formative for further actions.

The teachers' manual, professional development resources, and other support materials are available in.pdf form. Teachers can use an online portal to create accounts for each student's avatar, to show groupings into teams, and to give various permissions (e.g., chat with team members, access to parts of the world).

To complement the MUVE with VR, the Unity 5 source code will need to be configured to work on a mobile phone, since the delivery platforms currently affordable at scale in classrooms are devices similar to Samsung's GearVR and Google Cardboard. An important decision in terms of capability is whether the VR app can function completely on the phone, or is connected to a server. The former is easier in terms of implementation, but would have less functionality (parallel to EcoMUVE stand-alone vs. EcoMUVE server). In either case, when a VR session was completed, the phone or server would need to send information to the computer on which the student is working, so that the two experiences were aligned in terms of what has and has not been done (e.g., field guide entries, data collected).

To enable a user-interface in VR appropriate for that medium, access to interface features such as the data collection tools would be toggled off and on by the student, so that presence in the virtual world would be undercut by activation buttons in the visual field. Also, all MUVE-based text boxes generated by clicking would be replaced by audio files. For example, when clicking on a non-player character, instead of a text-box appearing, a spoken response would be heard in the headphones. These would be appropriate to each situation (e.g., a young man's voice for Manny the landscaper, a neutral voice for the fertilizer ingredients). When activating a complex visual artifact like the Atom Tracker, the text would be read, and the full artifact would be stored in the Notebook for later analysis outside of VR. In contrast, brief numeric information (e.g., a turbidity reading for the pond) could be displayed as it is in the MUVE interface.

Given the constraints of space in classrooms, movement in the VR world would be virtual, as it is in the MUVE, rather than physical movement by students with analogous displacements in the virtual world displayed to them. Also, to avoid simulator sickness, a student's time in VR should be limited.

8.2.4 *Use-Case for EcoMUVE Pond*

Below is described a typical scenario of a teacher using EcoMUVE Pond in her classroom, alternating among the VR, MUVE, and monitor-based interfaces.

Part I: Getting to Know the Pond Ecosystem Starting in VR, students begin by visiting the pond and becoming familiar with the species living there, the surrounding environment (abiotic and biotic), and the local residents. When students first visit the pond, they are most likely to pay attention to the things that they can readily see: the fish, the frogs, the surrounding vegetation, and so forth (Grotzer et al., 2014). In VR, important sensory inputs can be made more salient: the color and turbidity of the water, weather variables like cloudiness and wind, shifts in the color of grass, the slope of the land, and the degree to which large fish are staying near the surface. Sounds also provide clues about variables like population density, and VR can enhance sound through 3-D location and variations in intensity by proximity to the source.

But soon students find out that, as ecosystem scientists, they must also attend to things that they cannot see. Transitioning out of VR to MUVE, using the submarine tool invites students to consider organisms that are invisible at the macroscopic level: the many thousands of phytoplankton and zooplankton that play a critical role in the pond ecosystem. By zooming in on these microorganisms, they will discover a new world—so tiny that they cannot see it with their own eyes, but one that is essential to life in and around the pond. On the second day, students will learn about the energy relationships between these organisms by using the Food Web tool as a monitor-based activity.

Part II: Measurement and Monitoring In the MUVE, students will be introduced to the measurement tools for water, weather, populations, and the calendar tool so that they can make observations and collect measurements on different days of the simulation. Students will work in teams; within a team, each student has a different role and must become an expert in certain aspects of measurement and monitoring in the virtual world. Students develop their expertise by using the monitor-based Learning Quests to gain an introduction to the major components of water quality. Once students have completed the Learning Quests, and thus achieved a working knowledge of water quality metrics, they may monitor these metrics during the course of the module.

Shifting to VR, students will observe that after a period of relative consistency, the numbers of phytoplankton begin increasing over time. Some students will wonder why, while others will miss this clue entirely. As events unfold, this dynamic could become part of a class discussion about why steady-state monitoring is so important in understanding and managing ecosystem relationships (Grotzer, Kamarainen, Tutwiler, Metcalf, & Dede, 2013).

Eventually the students should all notice that the phytoplankton is increasing; it will become obvious as the water of the pond becomes greener and greener. What the students are noticing is the process of eutrophication. Characterized by domino causality, the increase in plants leads to an increase in organisms that depend upon green plants. It also leads to increased decay as the plants die. This, in turn, leads to an increase in detrivores, such as amphipods and caddisfly larvae. Students should notice changes in water measurements that they collect. If they are very observant, they might also notice that the water is becoming a little murky and the temperature in the pond is slowly rising.

However, there is something else happening that they cannot see, unless they leave VR and use the submarine tool. The increased plant decay also leads to an increase in bacteria, which are invisible to the naked eye—a non-obvious cause. The bacteria that are eating the decomposing plants are thriving, but they are also using up the dissolved oxygen in the water.

Very soon, many of organisms that thrived because of the increase in green plants are gasping for oxygen. The most obvious of these is the fish (notice the fish are swimming close to the surface on July 25th). With lower photosynthetic production of oxygen and the use of oxygen by all of the bacteria, the fish are more desperate on cloudy days and there are more fish at the surface, particularly just before dawn. When the students visit the pond on July 28, there are dead fish along the shore. Observant students will notice that the fish kill followed a couple of cloudy days without wind.

Part III: Figuring Out What is Going On Using monitor-based tools, when students have collected all of the data, they will start to notice patterns in the graphs of the data over time. Students may notice changes in phosphates, nitrates, chlorophyll a, oxygen, turbidity, weather variables, and population sizes. These changes are related to one another and many of these changes give hints about what caused the fishkill.

In order to put the pieces of the puzzle together, students are asked to examine what variables have changed over time. In efforts to explain why these changes are happening in the pond, the students will draw on observations and information they have gathered elsewhere in the environment. The EcoMUVE environment provides an open forum in which students can use scientific inquiry to pursue their own path of discovery. Below we provide a few potential paths by which students could uncover important parts of the fish-kill story.

In VR, as the students visit the pond on different days, most notice dramatic changes in the color of the pond. By talking to one of the people in the world, the students find out that the pond is not usually so green. Students may wonder what is causing the pond to be so green. By using the water measurement tools and the submarine, students will learn the connection between the green color and the tiny floating plants (algae) in the pond. They realize that the pond is so green because the algae population has increased.

Using the data tools, students may also notice that the level of the phosphates changed quite a bit over time. As students try to understand why the phosphate concentration changes over time, they may notice that the fertilizer that is being used in the watershed contains phosphate. During their first visit, they see the landscaper preparing to apply a fresh load of fertilizer to the lawns near the pond.

Students who visit the pond on July 6th will notice that there is plenty of rain falling near the pond.

Transitioning out of VR, then reading the information on the fertilizer bag, and gathering information from the Atom Tracker tool, students will learn that phosphates that have not been used by plants can be washed off of the ground when it rains. The Atom Tracker tool will also help students recognize the critical role that phosphate plays in supporting the growth of plant populations. Thus, students will discover that phosphates likely had something to do with why the algae population increased.

Using the population tool, or by observing organisms in the submarine, students may notice a dramatic change in the number of bacteria that are in the pond. The bacteria population increases many-fold just days before the dead fish are found. Because many students recognize that bacteria can cause diseases, some students may think that the bacteria caused the fish kill. When students use the Field Guide to learn more about bacteria they will find out that many bacteria that live in ponds are decomposers. Students may begin to think of the increase in bacteria as an effect rather than a cause. Students will learn more about the role of bacteria through the Atom Tracker and field guide and find out that bacteria thrive on dead plants and animals. Students will also discover that bacteria use a lot of oxygen during the process of decomposition. With this new information, the decline in oxygen on July 25th begins to make sense.

In VR, students may also notice that not all the fish died between July 25th and July 28th. On July 28th, students can still find fathead minnows in the pond. Transitioning out of VR, if students use the Field Guide to learn more about fathead minnows, the students will find that these fish happen to be tolerant of high temperatures, high turbidity, and low oxygen concentrations. This may give students a clue about the variables that might have caused the other fish to die. The change in dissolved oxygen that immediately precedes the fish kill may be a strong connection that draws the students' attention. Further, the Atom Tracker tool will give the students clues about the importance of dissolved oxygen for fish health.

Thus, in keeping with authentic science, there are multiple pathways that students may take as they discover components that contribute to the fish kill. Rich hints and clues are provided through each of the tools and non-player character interactions built into the MUVE and the VR.

Part IV: Supporting Explanations with Evidence The final part of the EcoMUVE involves students in generating multiple possible explanations and working as a group to decide which hypothesis best explains the fish kill. The process of exploring multiple explanations challenges students to support their ideas with evidence; the teacher provides guidance as needed to accomplish this. The group discussion will also help students construct an understanding of the pond ecosystem that incorporates the complex causal relationships highlighted above. Each group must then present their best, most-detailed explanation, along with supporting evidence, to the rest of the class.

Table 8.2 Illustrative series of daily lessons and support materials

Daily lesson	Support materials
Day 1: BioBlitz: How many species can you find?	
Day 2: Food Web online tool	http://ecomuve.gse.harvard.edu/foodweb/foodweb.html Food Web Worksheet
Day 3: Explore changes in the pond over time	http://ecomuve.gse.harvard.edu/Pond_LQ.html Learning quest worksheet
Day 4: Roles, learning quests, data collection	Group worksheet Role worksheets
Day 5: Atom tracker	What is an atom handout Atom tracker worksheets
Day 6: Ecological processes, looking at changes over time	
Day 7: Representing causal relationships using concept maps	Parachuting Cats into Borneo Story
Day 8: Using evidence to support claims about causal relationships	
Day 9: Building cases—groups work together on final concept map and prepare presentation	
Day 10: Class presentations, final discussion	

Below is an illustrative series of daily lessons (Table 8.2), assuming a 50 min class period each day.

Note that many days have associated handouts and support materials.

8.3 Research Dimensions in Contrasting the "Classic" and VR Versions of EcoMUVE

Parallel to studies documented by Gardner in his chapter, research is needed to establish whether using HMD-based VR for some parts of the ecosystems experience (the "blended" VR version) might be more effective than the current implementation with avatars in a MUVE (the Classic version). Doing these studies is important, because VR does not intrinsically make every experience better in terms of motivation and learning. In fact, indiscriminate usage of full sensory immersion could make an educational experience worse. For example, for some students:

- too much time in VR during a session could produce simulator sickness in some students
- the richness and immediacy of VR could be overwhelming, undercutting a focus on the aspects of the experience important for learning

- the lower visual resolution of VR could make detailed alphanumeric information difficult to read
- the cumbersome VR interface could make it difficult to perform tasks requiring sensorimotor control

These and other potential issues underscore that VR should be used only when it adds value. Research studies can clarify the extent and severity of each issue.

What might VR contribute to EcoMUVE? Possible benefits are listed below:

- VR may make more apparent the topographic characteristics of the watershed, such as the rise and fall of the landscape. This is very important in understanding ecosystems phenomena.
- VR may make the ecosystem experience seem more "real," through increasing students' presence in the environment, enhancing transfer from the virtual setting to the real world (Grotzer et al., 2014). In particular, as discussed earlier, sensory inputs like sounds, the color and turbidity of the water, weather variables like cloudiness and wind, shifts in the color of grass, and the degree to which large fish are staying near the surface could all be enhanced in VR.
- VR may enrich the aesthetics of the ecosystem, helping students appreciate its beauty and richness, motivating them to preserve natural settings by being good stewards.
- VR may increase the attraction that students feel to animals and plants in the ecosystem, motivating students to care about these species. This is more likely to happen if species in the virtual world are animated so that they move around, interact with each other, and respond to user proximity.
- VR may increase collaboration with teammates in the setting by enhancing interpersonal presence.

Research is needed to determine whether and how much these desirable outcomes and other potential benefits of VR actually occur, as well as what types of design strategies are needed to fully realize each enhancement. Based on the outcome of the studies outlined above, design heuristics can be derived for blending VR and MUVE/monitor-based experiences, drawing on the affordances of each interface as appropriate for that particular part of the experience. Our work with EcoMOBILE developed design heuristics for blending purely virtual environments with real world experiences (Grotzer et al., 2014).

8.4 Design Heuristics for Complementing MUVEs with VR

This section postulates design heuristics for converting a MUVE learning experience to a transmedia narrative incorporating VR. This list is suggestive rather than complete and is largely based on the case presented in this chapter—so other types of monitor-based virtual worlds may require different or extended heuristics in order to blend in VR effectively.

Relative Use of VR, MUVE, and Monitor Interfaces

- To enhance presence in VR, use artifacts in the world (e.g., opening a toolbox) as a means to access to display activity-triggering buttons and other non-immersive features that are constantly displayed on the edges of the MUVE.
- To enhance presence in VR, use audio communication for complex or extensive dialogue boxes displayed in the MUVE, storing those artifacts for later viewing on the monitor.
- To enable high resolution viewing, display tables and graphs on the monitor rather than immersively.
- To foster immersion and reduce unproductive shifts in equipment, develop the narrative to minimize transitions between the VR and MUVE/monitor interfaces.
- Given current technical limits, use MUVEs for in-world collaboration, but shift this to VR when possible.
- To reduce issues with simulator sickness, limit time of each session in VR to 20 min.

As a general design principle, VR is not necessary and often cumbersome for planning and reflecting activities (the P and R in the PAR cycle), but powerful for the Action phase.

Useful Features in VR to Enhance Learning

- To preserve an experiential record for later interpretation, enable taking and storing "screenshots."
- To heighten presence and authenticity, use 3-D sound location and vary intensity by proximity to source.
- To synchronize a user's experience across devices, enable transfer of information between VR and MUVE/monitor.
- To heighten authenticity and affective impact, animate the behaviors of entities in the world (e.g., animals), so that they respond to the proximity of each other and of the user.
- Given current limits on space in classrooms, make all movement in the world virtually triggered rather than controlled by corresponding physical movements by user.

Key considerations in these illustrative heuristics are presence, authenticity, transfer, saliency, and identity. As discussed in earlier chapters, *psychological immersion* is the mental state of being completely absorbed or engaged with something, and *virtual presence* (*place illusion*, discussed in Slater's chapter) a particular form of psychological immersion, the feeling that you are at a location in a virtual setting. As described in Jacobson's chapter, *Authenticity* has dimensions of context and activities (similar to the real world), as well as impact and value (educational outcomes are close to students' lives, satisfying real world needs).

Via rich stimuli and a 3-D point-of-view, head-mounted displays use sensory immersion to deepen psychological immersion and presence, and some of the heuristics above are designed to heighten this sense of presence. Further, if the immersive experience is not fantastical, but instead designed as parallel to the real world, VR can heighten a sense of authenticity.

Presence and authenticity are important for *transfer*, which is a key outcome in learning experiences (Dede, 2009). Transfer is the application of knowledge learned in one situation to another situation, demonstrated if instruction on a learning task leads to improved performance on a transfer task, typically a skilled performance in a real-world setting. A major criticism of classroom education today is the low rate of transfer generated by conventional instruction (Schwartz, Bransford, & Sears, 2005). Even students who excel in schooling often are unable to apply what they have learned to similar real-world contexts (Perkins, 1995). Authenticity and presence address this challenge by making the setting in which learning takes place similar to the real-world context for performance in work or personal life.

By themselves becoming part of phenomena, learners gain direct experiential intuitions about how the natural world operates. Instructional design can make those aspects of virtual environments that are useful in understanding scientific principles *salient to learners' senses*; and multisensory cues can heighten this saliency. Adding multisensory perceptual information can aid students struggling to understand complex scientific models (Dede, Salzman, Loftin, & Sprague, 1999). Providing experiences that leverage human pattern recognition capabilities in three-dimensional space, such as shifting among various frames-of-reference (points of view), extends the perceptual nature of a visualization. In particular, by using visualizations to make the important aspects of a complex experience salient to learners, then fading these special supports over time, learners can perceive the environment through the eyes of an expert (in EcoMUVE, as an ecosystem scientist would), and then transfer this capability to real world settings.

All these factors culminate in the evolution of learners' *identities*. The evolution of an individual's or group's identity is an important type of educational outcome for which immersive experiences situated in immersive media are well suited (Dede, 2009). Reflecting on and refining an individual identity is often a significant issue for students of all ages, and learning to evolve group and organizational identity is a crucial skill in enabling institutional innovation and in adapting to shifting contexts. Identity "play" through trying on various representations of the self and the group in virtual environments provides a means for different sides of a person or team to find common ground and the opportunity for synthesis and evolution. Immersion is important in this process of identity exploration because virtual identity is unfettered by physical attributes such as gender, race, and disabilities. Authentic immersive simulations increase the value of participants' explorations by providing realistic feedback on how the real world responds to various patterns of individual and group behavior.

In summary, VR is a promising medium for enhancing these and other aspects of immersive authentic situations. However, full sensory immersion must be used carefully to realize its full benefits. The design heuristics and research dimensions this chapter articulates are a step towards understanding the differential power of immersive media to deepen motivation and learning.

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Chapter 9
Systems to Support Co-creative Collaboration in Mixed-Reality Environments

Michael Robert Gardner and Warren W. Sheaffer

Abstract This chapter examines the use of mixed-reality technologies for teaching and learning, particularly for more active and collaborative learning activities. The basis for this work was the creation of the MiRTLE platform—the Mixed Reality Teaching and Learning Environment. We report on some of the lessons learnt from using this platform on a range of different courses and describe how different active/collaborative approaches were used. We also provide evidence of the effect of these different approaches on the overall student attainment and discuss the implications on the use of this technology. We then consider some of the technological research being done to develop these mixed reality learning spaces and the affordances offered by this approach. Finally we reflect on the tensions between the pedagogy and technology and consider the implications for the wider systems that support teaching and learning and co-creative collaboration in mixed-reality environments.

Keywords Mixed-reality · Virtual worlds · Blended delivery · Co-collaboration
Maker-spaces · Multi-user virtual environment

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9.1 Introduction

As discussed in the introductory chapter, the concepts of *immersion, presence and engagement* are clearly important aspects in the effective use of virtual environments in education. In a Multi-User Virtual Environment (MUVE), properly designing the virtual learning space to improve the immersive experience, enhancing the visual and audio capabilities to heighten a participant's sense of tele-presence and developing activities to engage participants in collaborative and active problem solving, as discussed in Kraemer's chapter, can all contribute to an improvement in student academic achievement within these spaces.

The notion of learning by creating new knowledge is enhanced when participants in a virtual environment collaborate to creatively solve problems that are designed to improve their knowledge in a targeted area of study. We call this process co-creative collaboration.

Early in our research efforts we observed issues with traditional classroom based video-conferencing systems that supported the belief that extending the virtual environment into the physical world of a classroom and bringing the classroom into the virtual environment could achieve higher levels of presence within such environments thereby improving student achievement. To address these issues our thought was to mix video streaming and virtual reality to create a mixed reality environment. We began a research and development program that produced a platform that we called *the Mixed Reality Teaching and Learning Environmen*t, or MiRTLE (Gardner & O'Driscoll, 2011).

While our empirical research supports the concepts on which MiRTLE is based we felt that it was very important that the technology be tested in the actual classroom in order to develop a broader assessment of the efficacy of this technology in education. We developed a cooperative research program with Saint Paul College in Minnesota, USA who agreed to construct and operate a large-scale implementation of MiRTLE, use it in a standardized first course in computer science and to record their observations concerning its utility. Also, as the initial research was based on using MiRTLE with the Health and Human Sciences department at the University of Essex, it was felt that this extended trial at St. Paul with the Computer Science department would also help to assess whether this approach could be generalized across different disciplines.

When designing any teaching activity the learning objectives should be first and foremost and should guide the use of any technology that is being used. Based on our research at Essex, the trials at Saint Paul and other experiments we feel there are particular challenges in designing effective learning activities using this technological approach (Gardner & Elliott, 2014). This chapter reflects on this initial work and suggests that when applying such technology we need to put in place *systems* that support not only the technologies being used, but also the wider pedagogical and behavioral aspects effected by this platform.

We begin this chapter by highlighting some of the challenges involved in designing effective technology mediated learning experiences. We then describe the

MiRTLE project and review both the qualitative and quantitative findings from the field trials at Saint Paul College and some of the other technological research being carried out at the University of Essex. We conclude by considering what the implications may be for the development and use of similar Multi-User Virtual Environments (MUVEs) particularly when used to support co-creative collaborative learning activities.

9.2 Building Better Learning Spaces

With a plethora of technological advances at our fingertips, we have the ability to increase access to technology and content, display content from the internet-of-things, visualize abstract concepts within immersive environments, interact with peers and colleagues remotely both synchronously and asynchronously, and the list goes on. Part of the difficulty with the rapid advances in technology is our ability to rapidly design, develop and research educational spaces on two levels. First there is a technical and infrastructure level that needs to be iteratively tested to understand the logistics behind delivering working immersive learning environments. Secondly, there is the need to address the use of these embedded technologies for the purpose of learning and the creation of pedagogical situations that harness the affordances of the embedded capabilities in a way that is meaningful for learning.

At the University of Essex the use of the laboratory classroom called the iClassroom (Dooley et al., 2011) has allowed for design and testing of new immersive environments to be completed in a real space and with real students, measuring the efficacy of the technical and pedagogical solutions. This experimental space affords the opportunity to refine and redefine what intelligent spaces look like and how they can best be used to maximize positive learning outcomes.

Moving forward, as we begin to better understand the affordances and iteratively create design guidelines, our hope is that eventually a prescriptive framework emerges that informs both the practice of technical development and also the deliberate incorporation of technologies into both the learning space and the pedagogy through which students learn. At a wider level, the intention is to have demonstrated how the research is addressing understanding affordances, structuring experiences, and creating constructivist, collaborative processes, in mixed-reality smart environments. Ultimately the aim is to create more engaging, effective and rewarding learning experience for students.

Taxonomies have been developed that describe the technical aspects of immersive technologies (such as Milgram & Kishino, 1994), in addition to frameworks for describing the learning affordances of virtual learning environments (mainly multi-user virtual environments) such as developed by Dalgarno and Lee (2010), but none have been able to sufficiently and completely capture the multiple levels and complex interactions between them in terms that can be beneficial to designers and researchers for accurately describing the technologies with which they are working and the affordances of those technologies for learning. Continuing this investigative journey into the design of immersive learning environments, and being able to better define and classify new tools and research is imperative.

9.3 MiRTLE

Our first project that combined real and virtual worlds was MiRTLE (Gardner & O'Driscoll, 2011). The objective of the MiRTLE (Mixed Reality Teaching & Learning Environment) project was to provide an online virtual classroom to augment live lectures. This was inspired by the observation that even if remote students were able to watch a live lecture remotely (for example using video conferencing or other similar technology), they often would choose to watch the recorded session instead. The main reason for this (as determined from observations of actual classes and interviews with teaching staff and students) was that there was very little perceived value in their participation in the live event, as often there was only limited means (if any) for them to interact with the people in the live classroom. This meant that the recorded version of the event usually offered an equivalent experience with the advantage that they could also choose to watch it in their own time. MiRTLE provided a mixed reality environment for a combination of local and remote students where both dispersed and local students are able to see and talk with each other, in addition to the teacher. The environment was intended to augment existing teaching practice with the ability to foster a sense of community amongst remote students. In this sense, the mixed reality environment links the physical and virtual worlds. Using MiRTLE, the lecturer in the physical classroom is able to deliver the class in the normal way but the classroom also includes a large display screen that shows avatars of the remote students who are logged into the virtual counterpart of the classroom. This scenario is relevant to any classroom event where not all of the participants can attend in person. Thus the lecturer will be able to see and interact with a mix of students who are present in both the real and virtual world. In terms of the conceptual framework for VR outlined in the Introduction (Chap. 1), MiRTLE is a Multi-User Virtual Environment (MUVE) (Fig. 9.1).

From the initial qualitative evaluation of MiRTLE at the University of Essex, based on a small number of live classroom experiments, valuable issues were identified that have implications for future uses of this technology. For example, it showed that there was the opportunity for impromptu and naturalistic social interaction between virtual and physically present students. Also from anecdotal evidence, it was clear that the teachers recognized the potential value of the system, reporting that once students are logged-in and settled, the MiRTLE environment had a minimal impact on normal patterns of teaching, and the teachers perceptions of the learning occurring in their teaching environment. It also suggested that MiRTLE could facilitate a breaking down of the barriers between the virtual and the physical, supporting more spontaneous social exchanges between virtual and

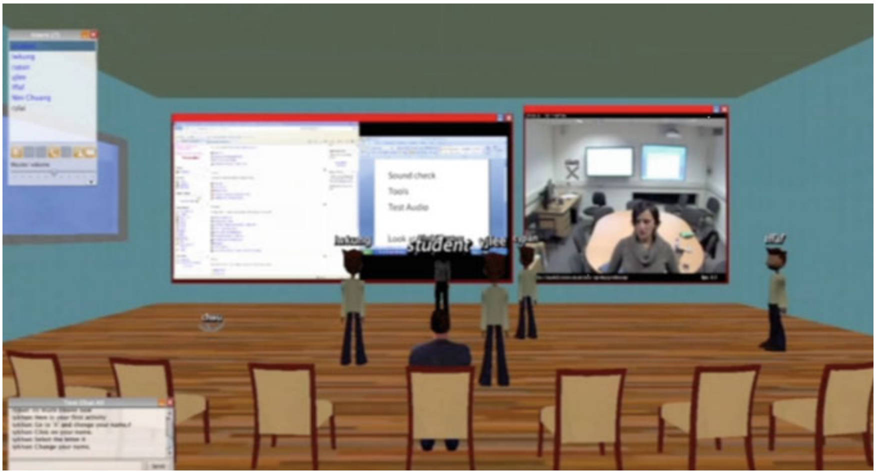


Fig. 9.1 MiRTLE classroom

physically present students, and increase the sense of presence for the learners and teachers involved.

9.4 Systems to Support Co-creative Collaboration in Mixed-Reality Environments

9.4.1 The Teaching Context—The Need for Blended Pedagogy Systems

Based on the initial research and the encouraging feedback from the use of MiRTLE at the University of Essex, we felt that it was important to carry out a more in-depth assessment of this approach in the classroom. We also hoped to better understand the wider pedagogical and behavioral aspects affected by the use of this technology. In this section we review the results of a field trial conducted over six years involving roughly 600 students in which the MiRTLE platform was utilized to deliver a standardized first course in computer science. During this trial the course syllabus, learning objectives, assessments, instructor and assignments were held constant.

During the 2008–2009 academic year the computer science department at Saint Paul College, MN, USA, implemented a MiRTLE installation in order to begin distance delivery of coursework.

MiRTLE was selected as the primary platform for distance learning for the following reasons:

1. MiRTLE brings the classroom to the distance learner and the distance learner to the classroom in a very engaging manner.
2. MiRTLE is a mixed realty platform that extends the virtual world that supports it. When this virtual world is not being used for lecture activities it can be easily utilized as a virtual world platform on which students and faculty can communicate and collaborate. See Gardner and O'Driscoll (2011).
3. Based on the Open Wonderland platform, MiRTLE easily supported the typical teaching tools used in a first course in computer science.
4. With a properly configured client computer MiRTLE is easily accessible and simple to use.
5. A MiRTLE installation can support alternative platforms such as Second Life or OpenSim with very little effort.
6. A MiRTLE facility is not disruptive, it does not require the faculty or students to significantly change their educational routine.

A general-purpose classroom was remodeled into a MiRTLE classroom in 2008. The general arrangement of this classroom is shown in Fig. 9.2. Life size avatars are projected on the rear wall of this facility and lectures are captured and distributed using an inexpensive security camera mounted on the ceiling of the classroom. For a wider discussion on the general infrastructure for virtual and augmented reality in the classroom see Richards (Chap. 6).

The field trials began following the construction of the MiRTLE facility.

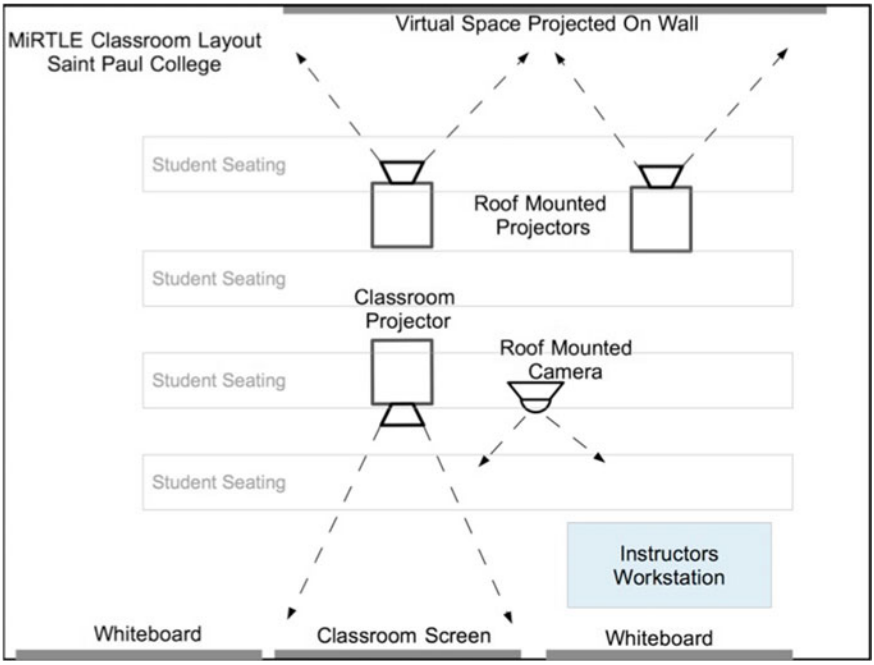


Fig. 9.2 MiRTLE classroom layout

Two measurements were considered reliable indicators of student success and data was collected on these:

1. Student achievement—measured by the improvement in the score on a standardized examination administered during the first class meeting and subsequently used as the final examination in the course.
2. Student retention—measured as the percentage of students attending the course relative to the initial enrolment in the course.

The first field trial began in September 2008 and ended in May 2010 that involved two class-groups per term for four terms (8 cohorts of 30 students) for a total of 240 students. Data from the eight class-groups was aggregated.

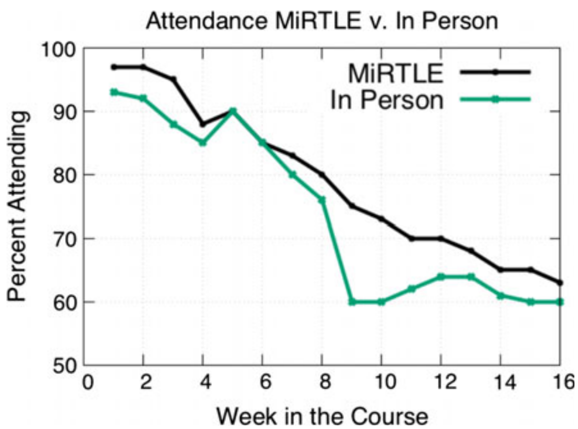
Based on the aggregated data, first meeting scores on the standardized examination were around 30% and end of term scores were around 75%. For those attending physically in the classroom the ending scores were 75.3% and the MiRTLE attendees scored about 74.4%. This seemed to indicate that there was essentially no difference in achievement between students learning on the MiRTLE platform and students who attended lectures.

The overall retention of students was about 61%. Weekly attendance trends are shown in Fig. 9.3. As can be seen, retention was slightly better over the course of the term for the students attending via MiRTLE.

During this trial the classes began with about 15% of the total enrollment indicating that they would be attending via MiRTLE. Over the course of the term students who planned to attend the classes in person began to migrate to the virtual platform. The attendance by the end of the term was typically 40% attending virtually and 60% attending in person.

We feel the results show that MiRTLE when used in this manner provides distance students with similar learning outcomes to those in the physical classroom. This is considered a successful trial since MiRTLE met all of its design expectations, with students performing as well on the MiRTLE platform as in the lectures

Fig. 9.3 MiRTLE retention



and it appeared that as students became more comfortable with the MiRTLE platform they migrated to it.

Due to the initial success of MiRTLE the computer science faculty elected to run a second field trial beginning in September of 2010 utilizing the MiRTLE platform and a learning management system to offer the course in a blended delivery format.

The idea was to move the static curriculum content to the asynchronous learning management system and utilize weekly meetings to answer questions and conduct lecture reviews of the material for the week. Students were also encouraged to attend the weekly meetings remotely using the MiRTLE facility and to meet virtually on it to collaborate on problems together.

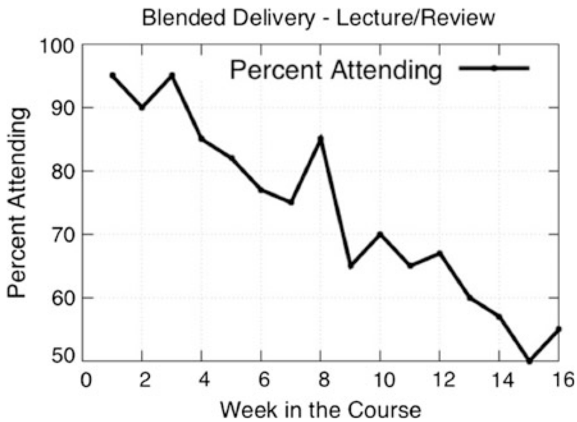
The second field trial was terminated in May of 2011 due to lower student retention and measureable decreases in learning achievement. The frequency and nature of student complaints and interventions by the college administration also played a role in electing to end the trial. The data gathered from this trial involved 4 class groups over two academic terms with 4 cohorts of 30 students each for a total of 120 students. Data from the four groups was aggregated.

Based on the aggregated data the first meeting scores on the standardized examination were again around 30%. However the final examination scores dropped from 75% as observed in the first trial to 63%. Overall student retention dropped from 61 to 52% of initial enrollment. Students made little or no use of MiRTLE and did not utilize the virtual world meeting rooms available to students in these sections as in the earlier trials with MiRTLE. The retention experience is shown in Fig. 9.4.

This outcome was obviously worse than the previous computer science courses that used MiRTLE for synchronous instruction. A lengthy retrospective review was done which included students who had dropped the blended courses, participants from earlier field trials and students and faculty who participated in a similar trial within the mathematics department. The following are considered key findings from this:

1. There appeared to be a critical coupling between pedagogical design and the technological platforms used in the course.

Fig. 9.4 Blended delivery lecture review



2. The weekly review sessions in the blended sections were essentially useless if as few as 10% of the attendees had not prepared for them.
3. The failed in-person sessions were the primary source of student complaints and were very disruptive to course conduct.
4. Students abandoned the use of MiRTLE and collaboration within the virtual environments due to their feeling of a loss of course structure.

Since MiRTLE had been successfully used in a traditional course during the first trial the group decided to re-examine the pedagogy in light of the technological approach being used. This led to the development of an alternate model of course design and a modification of the instructional pedagogy. This model envisions a course design of sequential learning modules that utilize a mixture of behaviorist and constructivist-based pedagogies. Figure 9.5 illustrates this general design.

This pedagogical approach utilizes active/collaborative learning laboratories for in-class instruction and divides online learning into behaviorist and constructivist learning activities. Behaviorist activities are primarily used for instruction in the lower order cognitive skills as identified by Bloom et al. (1956) they include knowledge, comprehension and application. The remainder of the online coursework which includes online discussions, online interactive laboratories and collaborative problem solving in the MiRTLE virtual environment, follow the constructivist paradigm. Constructivist activities are primarily used for instruction in the higher order cognitive skills as identified by Bloom et al. (1956) that include *create*, *evaluate* and *analyze*. They represent approximately 80% of all learning activities.

The computer science department began a third field trial in September 2012 which lasted through May 2014. This trial utilized the modified pedagogical model with the option of in-person or MiRTLE attendance. The trial involved two course

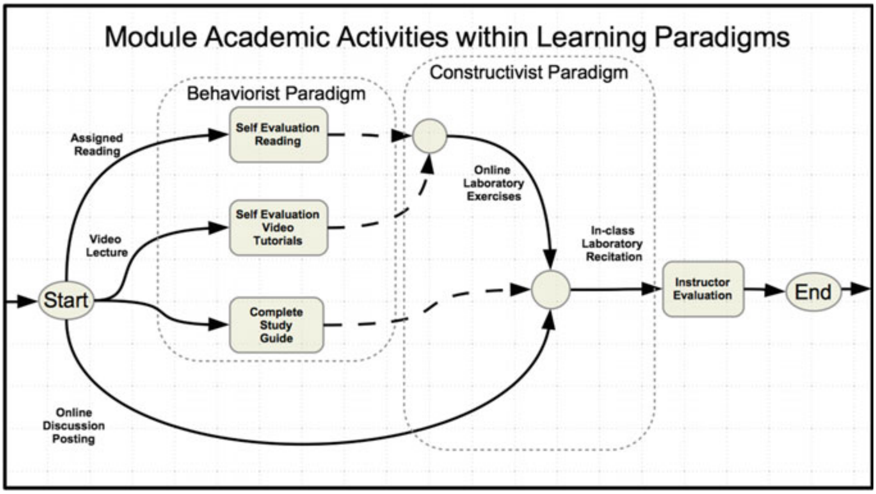


Fig. 9.5 Revised pedagogical model for a module

groups per term for four terms (8 cohorts of 30 students) for a total 240 students. Data from the eight groups was aggregated.

Based on the aggregated data, first meeting scores on the standardized examination were around 30% and end of term scores were around 81%, which was an improvement over the traditional lecture led classes. For those attending physically in the classroom the ending scores were 80.3% and the MiRTLE attendees scored about 82%, again both higher than in the traditional delivery format. This seemed to confirm the results of the first field trial that there is essentially no difference in achievement between students learning on the MiRTLE platform and students who attended lectures.

The overall retention of students was about 74%. This was a dramatic improvement over the second trial that utilized blended delivery and also an improvement over the first trial which used a traditional delivery format. Weekly attendance trends are shown in Fig. 9.6. As can be seen, retention was slightly better over the course of the term for the students attending in person rather than with MiRTLE.

Table 9.1 summarizes the student achievement based on the increase in their raw scores on a standard exam given at the beginning and conclusion of each course section, and the end of term retention rates of those students who were initially enrolled in the course.

Based on these experiments, we believe the following observations are relevant.

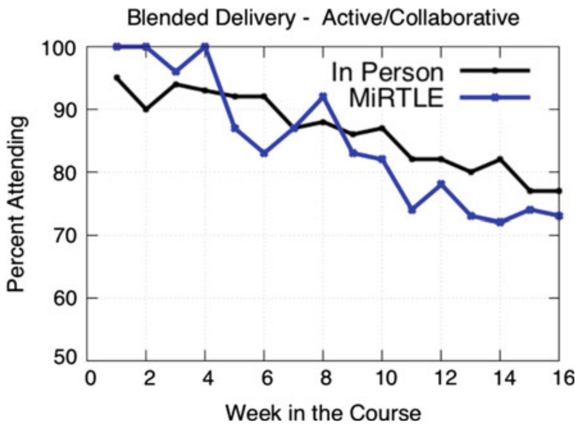


Fig. 9.6 Blended delivery—active/collaborative

Table 9.1 Comparison of student achievement

Student retention and achievement			
Configuration	Trial period	Student achievement (%)	Student retention (%)
Traditional	2008–2010	45.3	60.4
MiRTLE	2008–2010	44.4	62.8
Blended—lecture	2010–2011	33	51.8
Traditional—active	2012–2014	50.3	75.8
MiRTLE—active	2012–2014	52	72.1

Traditional or blended coursework utilizing the MiRTLE platform for remote students had learning outcomes similar to those who attended the course in the physical classroom. From the anecdotal evidence collected, we believe the effectiveness of MiRTLE lies in the level of presence the learner has within the virtual classroom environment, the ease with which the participants adopt the technology and the relative ease that learners using this platform have in interacting with other people in the lecture hall.

A simple unifying observation can be made for the tests conducted at Saint Paul to date. When implementing any system of technologically supported learning, care should be taken to consider the overall course delivery mechanisms, systematically recognizing as key system components the nature of the platform, the structure of the pedagogy and the capacity of both students and instructors to adjust their respective approaches to learning and instruction in the new environment.

9.4.2 Mixed-Reality Research at the University of Essex

A key finding from the Saint Paul experience was that it illustrated the clear benefits from using a constructivist learning approach, particularly when applied to active learning and creative problem solving, as discussed in Schneider's chapter. This also resonates with the technological research being carried out at the University of Essex. In Gardner and Elliott (2014) it was reported how our research addressed the core themes of understanding affordances, structuring experiences, and creating constructivist, collaborative processes, in mixed-reality smart environments. This was based on the iClassroom testbed and included the use of MiRTLE and the BReal Lab which is described below. In this section three areas have been highlighted relevant to the topic of this chapter. Part one will discuss the work on extending the capabilities of the original MiRTLE platform, the second part will examine the development of co-creative maker spaces, and the third area will examine how to use these spaces as a lens for the assessment of the learning outcomes of students in mixed-reality environments.

9.4.2.1 Extending MiRTLE

In addition to the University of Essex and Saint Paul College, other institutions such as the University of Hawaii have had success in deploying their own MiRTLE installations. The University of Hawaii is carrying out innovative work (Schmidt, Kevan, McKimmy, & Fabel, 2013) to extend the MiRTLE concept. For example, their HoloDeck system allows physically present students to interact with virtual students by using a mobile tablet based application.

The University of Essex is expanding the fairly limited instructional pedagogy supported by the original MiRTLE platform to include more collaborative learning activities, and incorporating a range of mixed and augmented reality technologies into the MiRTLE learning space. The work also aims to enhance the collaborative learning processes through the use of a variety of different user interfaces such as tablets and immersive glasses to enable a greater level of collaboration and communication between a range of users that include expert and novice students. A similar approach is described in Dede et al. (Chap. 8) where a range of research questions for comparisons between a VR and “Classic” version of an educational simulation are presented together with some generalizable design heuristics for blending MUVE-based curricula with head-mounted display devices.

A new platform has been developed (dubbed MiRTLE+), which enables a group of four learners with different levels of expertise (two novices and two experts) to collaborate on the same task at the same time. For the purposes of this initial study, the learning task was chosen to be a commonly used card game called UNO. The UNO card game was chosen as a learning task because of its relative simplicity and due to the fact that card games are commonly learnt by practicing with experts rather than reading from books or manuals.

In this scenario, the players work in pairs with the intention that the novice player can learn the game and associated playing strategies by observing their partners game play. The novice will also learn the game rules by communicating with their team member (the expert). Based on this learning activity, we have divided the group into four possible scenarios. This division is based on two factors; the students’ location (real or virtual world) and their level of expertise (expert (E) or novice (N)). This is used to determine whether their location (in the real or virtual space) has an affect on the learning outcomes and their overall performance. Figure 9.7 illustrates these different evaluation scenarios.

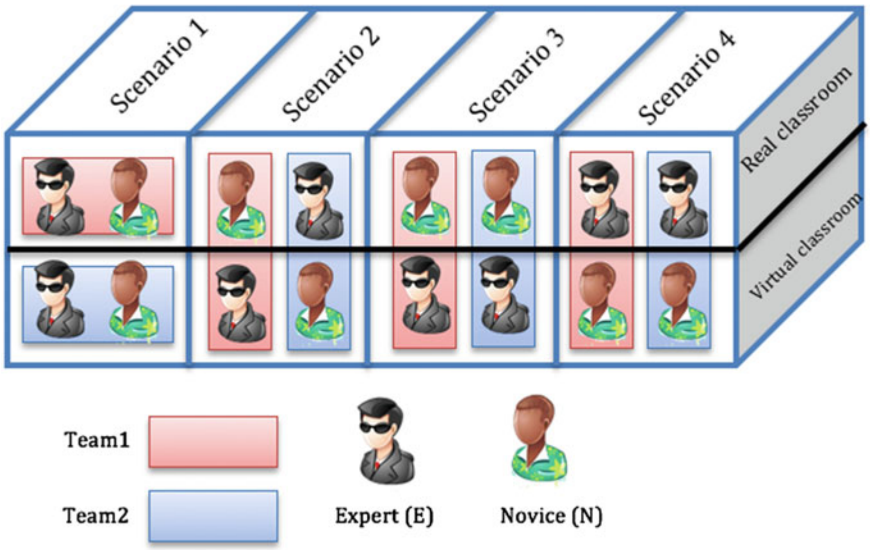


Fig. 9.7 MiRTLE+ evaluation scenarios

The iClassroom smart environment supports this interaction by using a range of augmented and mixed reality collaboration tools. This forms the basis for quantitative and qualitative evaluation studies that measure the learning effectiveness of the new mixed-reality environment. With regard to the evaluation techniques, the evaluation of the students' sense of presence includes the use of a subjective questionnaire that have been customized and extended based on the Presence Questionnaire (PQ) developed by Witmer and Singer (1998).

In the first phase (see Fig. 9.8), where students used tablet computers (for an augmented reality view) and PC screens (for a mixed reality view), the initial results showed that the immersive platform was more effective in promoting the novices' knowledge of the basic and strategic rules for UNO, than novices who played and learnt using a traditional web-based approach. The analysis also indicated that there were statistically significant differences in the levels of presence between the groups: which included a control group, a web group and the experimental group.

In the second phase of the evaluation, the augmented view within the tablet was replaced with an augmented reality headset (MetaOne) and the virtual world view with an immersive Oculus Rift headset which is used by the remote learners. Figure 9.9 presents the results from the evaluation of the student's sense of presence between the main groups. This clearly shows that the face-to-face control group had the highest score, followed by the phase 2 MiRTLE+ system, then the phase 1 MiRTLE+ system and finally the web-based group. These results clearly indicate that the more immersive technologies had a positive impact on the student's sense of presence when participating in the learning activities.

In both phases of the evaluation the overall findings are that the learning effectiveness and the students levels of engagement in the learning activity were significantly higher when using the augmented reality and immersive devices when compared to the web-based group. This is illustrated in Fig. 9.10, which shows a comparison of the learning effectiveness of the phase 1 and 2 MiRTLE+ platforms with a web-based group and a control group (which met face to face). However, as expected, overall the students who worked together face-to-face performed the highest. This probably indicates that the augmented and immersive technologies

Fig. 9.8 MiRTLE+ augmented and virtual worlds

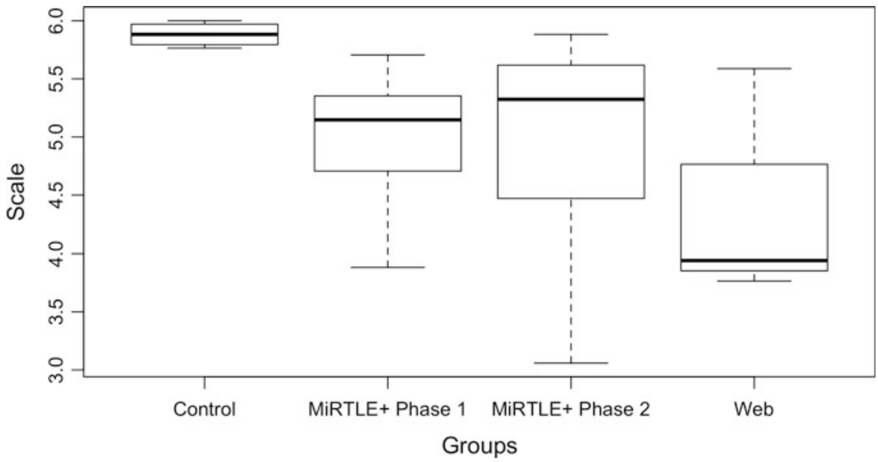


Fig. 9.9 Measuring presence between groups

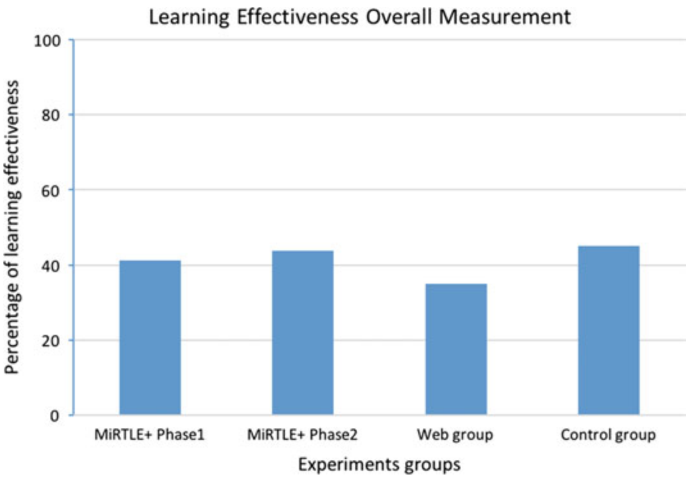


Fig. 9.10 Comparing learning effectiveness between groups

still have some way to go in order to fulfill their potential, but there are clearly some advantages when compared to less immersive web-based interfaces.

9.4.2.2 Mixed-Reality Co-creative *Maker-Spaces*

We believe the next generation of e-learning can bring with it a fundamental shift towards informal, interactive and business driven learning, away from the more traditional formal e-learning approaches. This will be accompanied by a host of opportunities and challenges for both the learners themselves and the institutions delivering the courses.

Many successful examples exist of project-based collaborations built by multi-disciplinary student teams that transcend this. For example, children in coding clubs (e.g. coderdojo.com) mentor each other using programs like Scratch and have subsequently self-organized to build teams to compete in robotics competitions. Undergraduates in engineering courses collaborate with business students to create new product prototypes; often these projects emerge from undergraduate work and evolve towards competitive programs, and may then be reinvented as postgraduate projects.

Maker spaces are a type of non-formal learning environment more active in technology orientated, and other more informal creative and innovative tasks. These workplaces have the potential to bring together people with common interests in technology, computer science and digital art to socialize and work. Typically all of the participants will have the common motivation for creativity, commitment to innovation, openness to collaboration and the promotion of experiences of learning by doing (rather than being required to use the space as part of a formal learning task). Here, new and flexible concepts of virtual laboratories and virtual experiments offer an appropriate platform for education and communication. Examples of current *Maker space* initiatives in Europe include Madrid (e.g. medialab-prado.es), Barcelona (e.g. vailets-hacklab.org, codeclubcat.org), Toulouse (e.g. tetalab.org), Lisbon (e.g. fablablisboa.pt) and Porto (e.g. opolab.com).

In the last decade a number of fully software based virtual laboratories in different fields have been developed. In most cases they are specific to an educational context and do not offer possibilities for generalization to a platform applicable to a wider class of disciplines (Potkonjak et al., 2016). This has led to the emerging idea of using virtual environments that enable exploration of new challenges and conceptualisation of solutions through collaboration. This *Maker space* concept includes a range of creative, design and end user engagement toolkits as well as models enabling the use of a range of scientific tools, which could be composed and implemented in an appropriate virtual laboratory. For example at the University of Essex we have developed the '*BReal Lab*' (Peña-Rios, Callaghan, Gardner, & Alhaddad, 2015—see Fig. 9.11) which provides an innovative approach to enabling geographically distributed learners to collaborate around physical engineering laboratory activities, such as building robots. This mixed-reality space allows students to share both virtual and physical electronic components in order to jointly create new robotic applications (as distinct from how MiRTLE used audio and video as a mixed-reality medium). It facilitates the combination of software and hardware components, created by different students in different parts of the world, into a single working system. The BReal Lab has been successfully tested with a range of groups of dispersed learners and the preliminary results (Peña-Rios et al., 2015) showed a positive learner's experience opening up new opportunities for online education.

Fig. 9.11 BREAL mixed-reality *maker space*

9.4.2.3 Virtual Observation Lens

There are many issues involved in creating meaningful collaborative learning tasks, including task allocation, communication, evaluation and assessment. Working with peers is not just a matter of gathering people together; successful collaboration depends on who the members are, what the tasks are and how the members are assessed individually and as a group. Learners usually acquire new knowledge while practicing learning activities. Consequently, rather than looking at the final product as evidence of learning, instructors should assess the whole process. However, collecting data to trace the students' behaviors in 3D virtual environments is typically more challenging than in face-to-face traditional learning sessions (Chiang & Schallert, 2012).

Several issues can arise in assessing a group of learners in these environments. First observing the users' behavior dynamically and collecting evidence of learning can be challenging when using a virtual world. The main problem is the abundance of data generated by the VW. Secondly numerous skills, such as communication and negotiation skills could be gained by students when working on collaborative activities, however often it is difficult to automatically detect this type of evidence in these spaces. Third labeling and recognizing the evidence of individual users in real-time is particularly difficult where several learners are contributing at the same time, which makes automatically tracking performance difficult (however, this can also be true in real-world settings). Some of these issues were highlighted by Gardner and Elliott (2014), in which we found that "learning within technology creates a pedagogical shift that requires teachers to think about measuring outcomes in non-traditional ways".

Shute et al. in Chap. 5 examines the role of diagnostic assessment in immersive learning environments by introducing the concept of stealth assessment, and provides an example of stealth assessment within a game environment. Our research (Felemban, Gardner, & Callaghan, 2016) is also exploring stealth assessment mechanisms but within a multi-user environment. We are aiming to create a novel computational framework that enhances the observation and recording of collaborative learning activities in order to evaluate the individual and group learning outcomes. In particular, the aim is to create a virtual observation model that can map between observing and evaluating students in physical settings with observing and assessing them in virtual worlds. The focus is more on providing methods to identify and classify learning evidence and assess group working than mapping all these elements to specific learning outcomes. To do so, we use an agent-based approach to support the recording and labeling of learning evidence from virtual activities and therefore simulate the observations normally made by a teacher.

At this time, the BReal Lab (see above) has been extended to provide a number of tools to address these issues. The platform utilizes techniques from multi-agent systems to track users' actions and predict the learners' acquired skills and knowledge. It has two different kinds of agents: software agents and natural agents. The software agents track learners and collect different users' clicks and actions, while the natural agents allow users to perform peer evaluations of each other to evaluate the quality of their performance. When the students are taking part in learning activities, they will be asked to act as agents and evaluate their peers via a sliding rating scale. A key issue will be to avoid any unnecessary disruption or cognitive overhead whilst the students are doing this. These agents are employed to record both implicit and explicit data that will be analyzed to determine the learning evidence and individual students' performance. The agents will communicate and work together in real time to collect this evidence, which will then be analyzed by a computational model based on the use of fuzzy logic. The intention is that this model will fully describe and map the characteristics of different learning objectives and will provide a mechanism to map between in-world events and individual learning achievements (based on the underlying data) through inferences derived from the fuzzy rule set.

The central part of this research is the *observation lens* model that will determine how to analyze the data that is captured by the agents. In normal practice in order to observe students in the classroom, educators should consider numerous criteria to gain an insight into the students' learning processes and outcomes. As a starting point the work of Borich (2016) has been taken to create a virtual observation model (see Fig. 9.12), which can be applied to the collaborative virtual world in order to evaluate the learning activities taking place. The virtual observation model

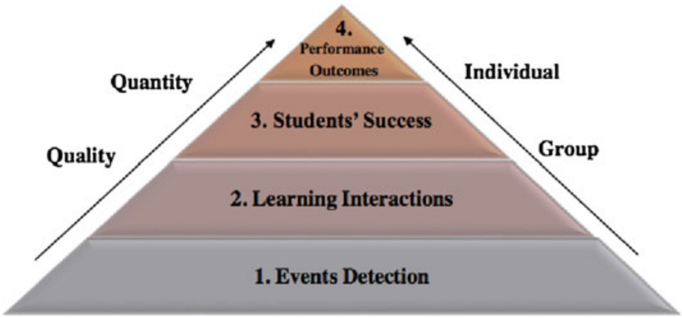


Fig. 9.12 Observation lens

defines different levels of granularity for observing students and recording evidence of collaborative learning, from high to low-level observations.

Starting at the lowest level, the first level of the hierarchy is the *Events Detection* lens that simulates an instructor who is watching a collaborative activity from a general viewpoint without looking deeply into the content of what is happening. In this level, the observer monitors the activity by understanding that a sequence of events is occurring and capturing these events without judging the meaning of the actions. It is envisaged that examples of the events that can be observed and collected from the virtual world activities will include avatar event logs, chat logs, object event logs and student self-rating logs.

The second level is the *Learning Interactions* lens, which considers a deeper view of the social and environmental interactions. The social interactions are between peers, and the environmental interactions are between students and the virtual world. Evaluating the quality and quantity of collaborations and interactions infers whether the learners have valuable interactions and if they are active learners in their groups. It also determines the amount of sharing and interaction among students. It is possible to infer the quantity and the quality of learners' interactions by creating fuzzy rules based on the teachers' viewpoint. Examples of these rules are:

- The number of a learner's contributions in the chat log during a period compared with other learners.
- The number of a learner's contributions in using the virtual objects during a period compared with other learners.
- The number of a learner's contributions in completing tasks during a period compared with other learners.
- The rating scores for a student from other members in a given period.

The third level is the *Students' Success* lens. It represents the actions taken by teachers when they are observing students' success by counting the number of correct answers; the number of right answers reinforced or acknowledged events, and the number of delayed corrections.

The fourth level is the *Performance Outcomes* lens. This level simulates the observer tracking students in depth to identify the skills and knowledge that they have acquired from the learning activities. Because our research focuses mainly on educating learners on technical subjects using collaborative learning activities, students can acquire both collaborative and technical skills based on the activity they are doing. Thus, this lens should help the virtual observer assess the knowledge and skills of the individual learners.

The first two layers of the observation lenses and the mechanisms to assess how best to translate teacher generated observation rules into descriptive logical rules are currently being developed. The plan is to determine the observing rules that should be created and when the rules should be activated. This will require the creation of a fuzzy model, which will be validated through a series of expert evaluations. In terms of assessing this approach for collecting learning evidence, the intention is to assess how much data should be collected to yield sufficient evidence of learning, and how much should be collected from natural agents and how much from software agents. In this work a determination will need to be made as to how different types of data can be automatically grouped to demonstrate meaningful evidence of learning.

9.5 Discussion

The Saint Paul case study clearly shows that the technology is only one part of the picture, and the other aspects (particularly behavioral aspects) are equally important when designing new learning activities.

This work has also shown that the mixed-reality approach can work well, particularly when incorporated into a sound pedagogical/behavioral approach. The evidence from the Saint Paul case study also reinforces this.

MiRTLE was deliberately very simplistic in terms of the pedagogy being supported (but effective because it was so simple). MiRTLE was successful not because it was technically advanced but because it was so natural for the instructors to use, requiring no new training or lesson planning. Effective use of any of these platforms in an educational setting is totally dependent on the structure of the pedagogy. Here pedagogy is king and technology is servant. This might explain the reason for the relatively slow uptake of virtual and mixed-reality where often due to the complexity of the platforms a lot of effort is spent on the technology and little effort on how to apply it. Here the relationship the technological system has to the environment it will be operated in is a key success factor. In addition the work being done at the University of Essex to extend the MiRTLE platform particularly with the use of new devices and more collaborative learning activities, shows great promise, and seems to lead to more engaging, and effective learning (when compared to more traditional approaches).

Once this approach becomes more embedded, it should then be possible to leverage more of the affordances of using virtual and mixed-reality spaces for learning. For example, the Essex work to create an assessment lens should help students and instructors better assess the learning outcomes achieved.

A key aspect arising from this work is the challenge of designing more effective virtual spaces for learning. Our research has shown some of the benefits from taking a more constructionist approach to learning. This is backed up by other research (Ross, 2013) that proposes a more student-centred pedagogy in which students are more involved and active in their learning and construction of knowledge. This has led to increased emphasis on active and collaborative learning activities and subsequently the creation of new *Maker spaces* (as discussed above) that incorporate a significant leaning role. The importance of the design of the environment on the learning outcomes is also reflected in other studies (Barrett, Zhang, Moffat, & Kobbacy, 2013; Perks, Orr, & Al-Omari, 2016), that have focused on changes to the physical environment of classrooms and schools and its impact on the students as a space for learning.

Designing and building effective online spaces can be demanding and time consuming for stakeholders and also often requires high levels of technical expertise. User customization has the potential to improve engagement and experience in virtual spaces, much in the same way as personalizing homes makes it feel and work better for its inhabitants. Thus, to achieve better online experiences, such 3D spaces need to be easier to build and well designed. Also, such environments need to provide its users with a rich experience and greater flexibility to suit their needs. Jacobson further discusses some of these issues in Chap. 3 where he focuses on the challenge of creating authenticity in immersive design as a principle for guiding authors of educational immersive media.

Recent studies have found that the influence of physical and psychological design parameters influence the users experience in built environments. These parameters are linked to the 'responsiveness' of such environments. Virtual worlds show great promise for increased visualization, immersion and enhancing the users' experiences but the current evidence suggests that they struggle to compete with their physical counterparts. One approach moving forward would be to capitalize on findings from the design of built environments to try to develop better designs that can be used beneficially in 3D online worlds. According to Bentley (1985) a built environment should provide its users with flexible settings and opportunities to maximize the choices available in their environment. Such environments with these affordances are said to be 'responsive' and can be characterized according to well defined architectural and user characteristics. The challenge in creating new mixed reality spaces for learning is to combine the benefits of good architectural design with the flexibility and customizability that is afforded by the use of these digital 3D spaces.

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Author Biographies

Michael Robert Gardner has a B.Sc. (Hons) in Computer Science (1984) and a Ph.D. in Computer Science (1991) from Loughborough University in the UK. Previously he worked for 15 years as a Research Scientist at the British Telecommunications (Adastral Park) research labs at Martlesham Heath in the UK. He then setup and became the Deputy Director of the Institute for Social and Technical Research at the University of Essex. Currently he is a Senior Lecturer in the School of Computer Science and Electronic Engineering at the University of Essex. In this role he is also Director of the Immersive Education Laboratory. He has published over 100 papers which include conference, journal and book articles. His primary research interests are in understanding the affordances of immersive education technologies and developing systems to support co-creative collaboration in mixed-reality environments. He is on the board of the newly created Immersive Learning Research Network (iLRNetwork), which aims to develop and support a community of educators, scholars, and practitioners dedicated toward research in and on digitally-enhanced immersive learning environments.

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Chapter 10
Massively Multiplayer Online Roleplaying Games and Virtual Reality Combine for Learning

Eric Klopfer

Abstract The places where Virtual Reality (VR) can really make a difference in learning are those in which the VR can bring a truly unique experience to students. The simulated online world of games is an ideal way to take advantage of the capabilities of this new technology. Games provide a set of structures that not only scaffold learners in solving complex problems but also provide a great deal of freedom to explore personally interesting pathways. In particular, Massively Multiplayer Online Role Playing Games (MMOs) offer an environment that supports social learning and exploration around increasingly challenging problems. VR can greatly enhance MMOs through opportunities for more natural and expressive communication and collaboration as well as ways to visualize the complex information resulting from interactions in this space. When this approach is applied in an educational context, learners can be presented with challenging problems, requiring participation from multiple players around realistic scientific concepts. As this genre moves forward it can explore interesting hybrid approaches that combine VR with Augmented Reality (AR) and traditional displays to meet the needs of schools, teachers, and learners.

Keywords Games · Learning · Science education · Collaborative learning

10.1 Introduction

I was recently reading an announcement (Whitmore, 2016) about a new school that will have virtual reality (VR) as a central theme. In discussing the ways in which they would use VR, this description was offered:

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> Imagine this: Students enter the lab, strap on a virtual reality headset (just like the HTC Vive Andrew [one of the people at the school] had me put on during a demonstration), and **instead of playing video games, students will enter a fully immersive and scientifically accurate virtual reality chemistry lab.** *They will see their lab partner, and the two will discuss what they will do in the experiment, just as students would do in a traditional lab.*
>
> Let's lay out a simple experiment: Does adding salt affect the boiling point of water? The student would reach out with hand controllers, take a graduated cylinder, fill it with water, measure out the salt, light a Bunsen burner, add a thermometer, track the boiling point — *and then repeat the experiment without adding salt.*

As new technologies are introduced, they are often initially adapted to previous practices. Going back in time, the first films were simply movies of live plays. Later films explored cameras that moved around, went outside and shot on location. And today we see a diverse use of this medium. More recently, we saw the first wave of Massive Open Online Courses (MOOCs) broadcasting videos of lectures (Papano, 2012). This medium has also started to change, incorporating more features of the unique online environment and scale that they offer.

So this usage of VR is a predictable initial foray for the technology. Before we dream up new kinds of interactive experiences, we recreate existing practices in a new medium (see Dede's "Old Wine in New Bottles"). While the pathway to such experiments may allow for rapid development, boiling water in VR is unlikely to lead to great advances in 21st century learning. Rather than recreating 20th century laboratory practices to demonstrate known phenomena, we should be doing exactly what this passage passes over. Instead of having students replicate those prior practices, they should be playing video games.

10.2 Why Video Games?

Why should students be playing video games instead of conducting labs? That is actually a false dichotomy. They should be playing video games and conducting labs. Some of those labs should be in real life. If Bunsen burners are unavailable, then draw upon kitchen science. Experiments in virtual reality can permit working in domains that are difficult or impossible to recreate in the real world. Experiments can take place on long time scales like that of evolution, at microscopic levels in chemistry experiments, or on the inside of a nuclear reactor.

But those labs can also be embedded in or connected with games. A game world can provide context, identity, and purpose for conducting such investigations and make the experience more meaningful and (while it might seem counterintuitive) it can also make them more authentic. For many students, isolated labs have little meaning. Breeding peas to determine whether wrinkled or smooth is dominant (long after Mendel established this) might seem quite routine. But breeding plants to find the variety that will help cure a (fictional) illness in an online world can situate the activity in a more personally meaningful context.

While some look to games merely to "make" an activity fun, their real advantage comes in providing structure around activities that allow for freedom and autonomy, yet also provide enough boundaries to help guide learners. There are many definitions of games, some of which focus on narrative, identity, or the separation of play and reality. My definition has focused specifically on the structures of games. These five principles describe these structures or "gaminess" (Klopfer, 2015).

- Interesting Decisions—This is Sid Meier's (the creator of Civilization) hallmark of game design. Good games are defined by the choices that players make. Deciding between heads and tails is not interesting, but making decisions that are informed by previous experiences and insights often is.
- Consequences to Decisions—There needs to be some set of consequences to the outcomes of the player's decisions. Those outcomes can be positive or negative, providing feedback to the player as to how those decisions are valued in the context of the game.
- Clearly Defined Goals—The game should provide a set of constraints and opportunities so that the player either knows a priori, or can easily discover what they are trying to accomplish. In good games, the player can choose between multiple different goals and can pursue them in a way that they see fit. For example, a player may choose to accumulate the most wealth, conquer the world, or broker peace.
- Visible Measurable Feedback—The player needs to know how they are doing. Ideally, they get this kind of feedback along multiple dimensions. This is not just a single measurement of score, but might include level of achievement, health, or gear that they have collected. This feedback may reflect "stealth assessments" that are a part of the game (see Shute in this volume).
- Underlying model or systems—There should be a coherent set of rules that define an underlying system. In digital games this might take the form of a simulation or set of simulations. But it can also be a comprehensive set of rules that define the mechanics of a non-digital system (Fig. 10.1).

There are many ways that these principles can be manifest in games. They could be provided through structured narratives, quest structures or other game systems and mechanics. Many great games embody many or all of these structural principles. These could be strategy games like Civilization, battle arenas like League of Legends, or Massively Multiplayer Online Role Playing Games (MMOs) like World of Warcraft. The latter is a particularly good example.

World of Warcraft (WoW) is a game set in a fictional world occupied by two warring factions consisting of fantasy races like elves, dwarves, orcs and even humans. Players choose a faction, race and class that specifies their roles, like a magical cleric or a hunter. They are then given a series of tasks to complete in the world by numerous non-player characters (NPCs) that inhabit the world. These tasks (or quests, as they are known) might be about collecting a certain number of items from a dangerous place in the world, or killing a terrible beast that has been attacking your folk. Players attempt to complete these tasks, granting them new

Fig. 10.1 World of Warcraft quest from http://www.mobygames.com/images/shots/l/91220-world-of-warcraft-windows-screenshot-the-quest-log-shows-you.png

skills and items. But they do so in a context that includes many other real players who inhabit the world. Most of those players are on the same side and are there to help. There are some quests that can only be completed by working with others. Such "dungeons" require collaboration with small groups. As players gain more experience they are challenged to collaborate in large groups (dozens of people) through "raids." Thus, the game exemplifies gaminess in the following ways:

- Interesting Decisions—The game offers players a variety of choices, beginning with their faction, race and class. As their characters level up, players need to continually make decisions about their specialization. While the world isn't truly "open" it has many places to explore and players need to choose where to go and what quests to take on. In battle, players choose from the array of abilities and weapons on hand to accomplish the task.
- Consequences to decisions—Succeeding in a quest leads to rewards. These include money, items and experience that can be used to level up. The more interesting consequences come from the choices about how to increase and specialize abilities. One can be a generalist, but at the cost of not being really great at anything. Or one can specialize in one domain, but be at a loss when another set of skills is needed.
- Clearly defined goals—For some players, WoW is about leveling up as quickly as possible. For others it is about obtaining some particularly rare item that can

be worn around. For still others it is about showing leadership within a group with whom one is collaborating. This diverse array of goals makes the game interesting to a range of players.

- Visible measurable feedback—On the way to accomplishing different sets of goals, Wow provides many levels of feedback. Players have wealth, items, experience, achievements, and reputation, to name just a few. Different players can choose to value these in ways that are personally meaningful and relate to their goals.
- Underlying model or system—WoW consists of many related systems. There are systems of weapons and spells. There are also systems that govern where and how often particular items are found. Discovering and debating the rules of those systems becomes an important thread in online discussions where players discuss their theories.

10.2.1 Educational Video Games—The Story of Radix

Many attempts have been made over the years to combine video games and learning. In some cases that means applying the superficial components of games like scoring or shooting to an otherwise mundane learning activity. The game Math Blaster exemplifies this kind of gamification. Math problems appear in the sky and the player needs to shoot down the right answer. There is no connection between the game play and the learning. The problems floating in the sky could just as well be vocabulary words.

Compare that game to The Logical Journey of the Zoombinis (Hancock & Osterweil, 1996), another long-lived educational math/logic game. But in this game the player never actually sees math problems. Instead, they solve mathematically modeled problems that are situated in a world inhabited by lovable creatures the player is trying to save (Fig. 10.2).

There have also been attempts at using commercial video games directly in the classroom. One such attempt (Steinkeuhler & Duncan, 2009) centered on WoW. In particular, it focused on the ways in which scientific discourse was incorporated into online discussion about the game. Players craft theories about how the systems work within the game and then collect and analyze data to test those theories. It might be about where the highest probability location for a particular item is, or the right sequence of spells to take down an enemy. Another topic was how players should best work together to accomplish complex tasks. Steinkuehler and Duncan found that many players used some fairly sophisticated theories and engaged in many levels of scientific discourse.

Players also invest a tremendous amount in their characters, developing them over months or years. At one point in time the most secure login system that I used was for my WoW character. It was more secure than my login for my bank, as I knew my character was nearly irreplaceable. That investment in the character immerses the player in the world in a deep and rich way. When that character

Fig. 10.2 The Logical Journey of the Zoombinis (https://external-wiki.terc.edu/display/ZOOM) showing a puzzle in which players must get all of the characters across the bridges based on an unknown logical rule

investment is combined with the social investment that players make—connecting to other players with whom they collaborate—it makes for a truly immersive experience.

Building on this idea, we (Clarke-Midura, Rosenheck, Haas, & Klopfer, 2013) created an educational MMO, Radix, about mathematics and biology. Radix is an MMO set on an earthlike planet in a Renaissance-like era of knowledge. Players take on the role of a novice in an underground society trying to use knowledge to make the world a better place. The quests that players take on relate to core content in either science or mathematics in one of several topic areas. For example, there is a quest line in mathematics that requires players to use geometry to reconstruct broken down buildings. Players are given tools that help them compute and construct the shapes that they need. Another quest line involves understanding human body systems. The player takes on the role of a physician who must isolate the system that is malfunctioning based on the symptoms patients present with. The challenge is to make these activities authentic, as discussed in Jacobson's chapter, even in a fantasy world.

Within each of these areas the quests get more challenging as the player progresses. A first challenge might simply be about understanding the underlying tool.

The next quest might be about applying the tool in a basic way. Each subsequent quest makes the challenge more difficult. Failure along the way results in another opportunity to complete the quest.

Radix was designed in such a way that those failures, as well as the successes, are informative. Many of the quests were built on principles of Experiment Centered Design (XCD) (Conrad, Clark-Midura, & Klopfer, 2014), a variant of Evidence Centered Design (Mislevy, Almond, & Lucas, 2003), which is also used in designing Stealth Assessments (see Shute in this volume). In XCD learners are challenged to conduct experiments. Each experiment provides results. Based on those results players can take further action, which might include further experiments. By interpreting these data we can deduce what students do and do not understand. For example, if a player is challenged to get "true breeding" (plants that breed to create plants with identical characteristics) medicinal plants, they would conduct a series of genetics experiments. If they breed two plants and get a mixture of offspring we can understand a lot based on what they do next—do they breed the offspring, go back and find new parent plants, or simply breed them again? This methodology gives the players a lot of choice and agency, but still allows us to better understand the model of the system that they have in their heads. In turn, the game can provide feedback to the students or their teachers based on these outcomes (Fig. 10.3).

Over time players unlock more capabilities in their characters and discover new parts of the world. They can also collaborate with peers and classmates on different

Fig. 10.3 Radix, an educational Massively Multiplayer Online Roleplaying Game (http://radixendeavor.org)

tasks, sharing data and knowledge to make the tasks more tractable. This form of collaboration, however, only scratches the surface of what is possible in these spaces.

10.3 VR + MMO + Learning

There is a huge potential for MMOs in VR. While some aspects of MMOs are adequately handled in 2D, or even better handled in this way, there are some aspects that can greatly benefit from this technology. Some early attempts already exist (see Looking Glass, 2016) and others are on the way (https://orbusvr.com). While Minecraft isn't an MMO, it shares some common facets, and it, too, has a VR version.

There are several reasons why MMOs in particular stand to gain a lot from VR implementations.

- **Immersion**—The most obvious reason is immersion, which I will interpret here as "investment." Part of the success of MMOs is immersion (similar to narrative immersion). There is the immersion in the character, social interactions and the world itself. Really being invested in a character means being invested in the world. VR can make the player a part of that world. A player becomes more invested in the fate of the world, the assets that they must protect or seize to accomplish their goals, if they feel that world is real. A player in a VR version of a game like Radix can benefit from the immersion in the character, interactions and the world, which are enhanced by removal of other distractions and a deeply connected first person perspective. See the world as if the player and the character are one can change the perspective of that player (see Slater in this volume).
- **Presence**—Presence is also fairly obvious and what I see as feeling like you are really in the virtual world. Complex tasks within WoW are notoriously challenging and require real time understanding of a multitude of data and factors. Screens of knowledgeable players (Fig. 10.4) contain dozens or hundreds of buttons, meters and heads up displays to keep them apprised of the situation. Bringing the player into the world allows them to experience and visualize that information in entirely new ways. Displays can be embedded in the world, or better yet, the ability to focus and perceive elements within the 3D space can be used to directly convey information for the player. The best representations and interfaces will need to be designed for these worlds to take advantage of the increased 3D perception, and situational awareness. For example in a game like Radix, rather than having detailed tools broken out into a zoomed in view in another panel, the tool could be used in context directly in the virtual world.
- **Collaboration**—The biggest possible contribution of VR to MMOs has to be around collaboration and social interaction (discussed in Kraemer's chapter). What really makes MMOs interesting and unique are the Massive and

Fig. 10.4 World of Warcraft raid interface showing the kind of displays and information players use. https://noggenfoggerblog.files.wordpress.com/2013/06/raidui1.png

Multiplayer parts. Sometimes that interaction is simply around two players who run into each other in some part of the world, exchanging ideas or helping each other on a task in which they are both involved. I've been continuously surprised and elated by the friendly help I receive from other players who just are passing by. In most cases the game is designed such that tasks become easier when players collaborate, encouraging this behavior. For example, players might be collecting unique samples of some flowers in the world. When two players encounter each other they might share some of the samples that they have each found.

Other times the collaboration is a lot more intense; every player in a group numbering dozens must coordinate their efforts down to a fraction of a second to take down "the boss," an opposing powerful NPC. In these cases information must flow through multiple channels, including not only the meters and displays shown above, but also audio and chat channels. In a game like Radix, this could be mean a biologist finding the genetic weakness of invading monsters, while a chemist creates substances that could attack those weaknesses.

But VR has the potential to make collaboration and social interaction much more productive and natural. This is why Facebook, the massive social network, purchased Oculus, one of the first producers of VR consumer hardware. They see VR as the next frontier for social interactions. Recent announcements (Lee, 2016) have started to give indications of what this will look like. Players might need to hold two sides of a lens to reflect light in the proper direction to activate a secret entrance, or simultaneously cleave a DNA segment to edit genes.

> While the typical Facebook interaction might be different than the kind of social interaction that makes up an MMO, many of the same principles will apply. It should be easy to see and understand the actions and expressions of your peers in the virtual space. It should be natural to interact with shared objects. It should be obvious what people are doing and where they are headed. These same traits are useful in an MMO.
>
> In fact, the next generation of social interactions in MMOs may look quite a bit different than the ones in current games. We may see more interpersonal and expressive interactions enabled by higher bandwidth, greater graphics fidelity, new controllers and VR headsets. MMOs might try to blur the lines between the game and the network of people working in the game so that other kinds of social interactions are supported, keeping players in the game world longer.

Getting back to the initial story on VR in schools, VR does show the promise of supporting greater collaboration around shared artifacts. Those could be test tubes filled with salt water for conducting a traditional lab. But a much more exciting opportunity is that those could be test tubes filled with alien DNA for analysis, or used to collect and analyze chemicals from a toxic waste site. These scenarios not only involve substances and scenarios that are unobtainable in real life, they can also be situated in a context that provides a rationale and in which the learner can immerse themselves. They can become something beyond a student in a class doing a lab, perhaps a scientist, adventurer, or pioneer (as illustrated in Dede's chapter). This is important for helping students develop an identity.

10.4 Innovation on the Horizon

So why aren't we seeing educational VR MMOs yet? There are a number of reasons. They require a lot of time and money to create, which means that before anyone can be successful in that space there are a few innovations that need to be worked out. One set of challenges involves the barriers that any MMO might face, which include the massive domain of content to be authored, which require authoring tools, which could be made accessible to individual content creators. Other VR specific challenges include:

- Interfaces—The existing set of interfaces for managing information and interactions within MMOs have been designed for relatively small flat screens. Yes, those can simply be ported to VR, but then there won't be a big advantage for VR. Instead, new interfaces that can both be situated in 3D space and that can display information in novel ways need to be created. People's abilities to focus on elements in the world and to perceive the relationship between information and objects will change in VR, and that can lead to exciting new visualizations.
- Controls—MMOs are notoriously complex and often require the use of the whole keyboard for navigation, use of abilities, and control of displays. Using a

keyboard with an opaque VR display adds new challenges to using this kind of control scheme. New VR controllers for navigating in 3D space and performing complex operations are starting to emerge. These controls need to be adapted to the space of MMOs to support the kinds of interactions they need.
- Settings/Context—Many MMOs are set in space or Tolkienesque lands inhabited by mythical creatures. But VR opens up the opportunity to situate these games in other kinds of places. They could be real societies, historical sites, or scientific microcosms. Being immersed in these kinds of spaces in VR becomes an exciting opportunity.
- Pacing—Playing an MMO is often a serious time commitment. Some MMOs have sought to break this time constraint by chunking play into smaller pieces. Being immersed in VR, particular when considering school context, likely needs to further advance this work of breaking play into smaller, manageable chunks of time.
- Collaboration—As mentioned above, this is perhaps the biggest and most exciting challenge for MMOs. What are the new forms of collaboration that can be fostered through VR in terms of social interactions and shared objects? Can players communicate with a nod of their head or wave of their hand? And can they interact with the same warp drive motor to try to repair it? This will make for rich game play and educational experiences. There may also be in-game and out-of-game collaboration opening up a range of mixed reality experiences. Perhaps one player is in VR, and the other is in the real world, feeding them live data through a mobile device that is incorporated in the game or simply using a flat display to provide a different perspective on the world.

10.5 Next Generation VR MMO for Learning

So what might a next-generation MMO for learning look like? I might start with a premise something like that of Radix, being part of a group trying to use science and math to make the world a better place. But perhaps it is set in the near future, in a world created through mapping and filming of actual cities. Ideally, this might be created via an openly shared mapping database that could be used for many VR applications, thus reducing the cost and barrier to entry for creating rich VR spaces for learning.

Given the current context, the problems to be solved might be based on real issues like fighting emerging diseases, breeding crops to cope with global climate change, or tracing the source of air pollution hundreds of miles away. Players might specialize in different domains like genetics, air quality, or data analysis. In the VR world, they can become that character, and take on that unique identity.

In one scenario, perhaps players need to manage an emerging disease in the southern United States (think something similar to Zika). They need to assemble a team consisting of someone who is role-playing a doctor, another who is a DNA expert, another who is an entomologist, and one who is a mechanical engineer, along with several others. They need to build a trap to collect mosquitoes for analysis and must collaborate to assemble the pieces and build the machine. They use specialized controllers to move the parts around, often requiring two people to lift together, and haptic feedback indicates when the pieces are in place.

Meanwhile, another team is collecting blood samples and analyzing them. Instead of using the traditional analysis tools, they can shrink down into the bloodstream and examine cells and molecules as they whiz by. One player needs to keep an eye on what is coming down the bloodstream and communicate to make sure the players don't get washed away.

Yet another team is in command central on traditional computers, monitoring the situation and advising the other players in real time. Flat displays might still be useful in the context of such activities as displaying maps, text, images and allowing seamless access to real world information such as laboratory equipment, documents, and peers.

The game might even include some Augmented Reality, relaying real time information to players' phones throughout the week. Augmented Reality (AR) can mean many different things. There is tabletop AR, as one might see through a specialized phone app showing a 3D model that pops out of a book, room scale AR, as seen on platforms such as Hololens, and landscape scale AR, which has been popularized in Pokémon Go. Landscape scale AR has quite a history in education (e.g. Dunleavy, Dede, & Mitchell, 2009; Klopfer, 2008; Squire & Jan, 2007). In much of this work, AR is used to add an interesting but fictional layer onto the real space, such as a school yard or nature center of museum, in which players are exploring. Also, in these experiences players work on teams to solve complex problems. The AR nature of the experience allows them to rely quite a bit on reality for communication using familiar devices like phones or face-to-face communication to work together.

In this case, blending in AR might mean that players can get updates on situations they are monitoring, and their own city might be a part of the problem/solution as well. So as they come to and from school, or go about their after school chores, they can be pushed new information based on their location and scan areas for problems/solutions using a simulated heads up display on their phone. This borrows from the genre of Alternate Reality Games that blend game play and the players' lives (McGonigal, 2008). Perhaps in this scenario players are combating an outbreak of a disease in the virtual world, but they can pick up virtual medical supplies at any of thousands of medical facilities geotagged across the country. Or perhaps players need to pick up certain elements only found in particular regions of the world and then share them within the game.

The teacher could also interact in a variety of ways. They could drop in through VR to experience what many of the students are doing, teleporting from one location to another. Many teachers might find it too difficult to immerse themselves in VR because doing so means losing sight of the whole class. A more likely scenario might be a single display on a flat screen. It will allow teachers to track what their students are doing in real time, allowing them to see who is struggling and who is succeeding and to offer students real-time assistance.

10.6 The Reality of School

Conducting an activity like the one described above in most schools would provide a significant challenge. For one, if they have VR capabilities, it might be on a single workstation for demonstration, or with relatively simple devices like Google Cardboard, which don't allow for highly interactive environments. It will be some time before schools have the technical capabilities and resources to conduct these activities. That means emphasizing one design principle—differential experiences on different devices. The kinds of hybrid activities in which some are in VR and others are on traditional displays can create immersive experiences that still draw upon the unique advantages of VR without trivializing the unique aspects of VR.

But there are more fundamental changes to both school and games that need to happen to facilitate this activity, as discussed in Richards' chapter.

First, the activity needs to be pervasive. If it is just a matter of short experiences in the computer lab, then these experiences will have little impact on student learning. The activity itself can be pervasive through mobile extensions and explicit connection to the curriculum. Students can monitor the scenario, communicate, and perhaps even launch automated exploration through mobile devices. This allows them to be immersed in the experience even when they aren't in VR.

Second, the activity needs to be persistent throughout the year, or at least a longer period of time. It will take some setup to make the activity work, and that investment in time can be justified by maintaining the activity over a longer period of time. Additionally, this persistence allows students to develop and explore their identity within the virtual space, investing the time and resources to specialize their characters and make them unique. This is the investment we see in commercial MMOs, and we should see similar investment in educational MMOs.

Finally, school needs to change some. These kinds of activities are great for getting students to take new perspectives, develop identities, learn how to collaborate around complex tasks, and challenge misconceptions. But it doesn't compress a lot of factual learning into a short period of time. Leading scholars and educators agree that that the kinds of learning promoted in this sort of experience is the kind of learning that we need to be offering students today. We just need to align that perspective with what actually goes on in school.

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Chapter 11
Embodied Education in Mixed and Mediated Realties

Some Results and Principles for VR Content Design

Mina C. Johnson-Glenberg

Abstract This chapter provides a summary of some of this lab's immersive media and embodied STEM learning research. It focuses on the integration of gesture in learning, and a new gesture-based assessment. A taxonomy for embodiment in education is included. The chapter concludes with several design principles that the Embodied Games Lab has culled over the years while creating educational content that maximizes the affordances of virtual and mixed reality technologies and meshes those with best pedagogical practices.

Keywords Mixed reality · Virtual reality · Science education Embodied learning · Taxonomy for embodiment

11.1 Introduction

This chapter provides a summary of some of the research ongoing in embodiment in education using both virtual and mixed realities, hereafter called immersive media (see introductory chapter for this book). It ends with several design principles that the Embodied Games Lab has culled over the years while creating optimal embodied educational content for mixed and virtual reality platforms. The term 'embodied' can mean many different things, here it means that learners are moving their bodies in a mediated environment in a manner that aids in comprehension; it encompasses using representational gesture as well as constructing models with virtual and real manipulables.

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Action and movement hold a special place for many educators. Maria Montessori writes, "Movement, or physical activity, is thus an essential factor in intellectual growth, which depends upon the impressions received from outside. Through movement we come in contact with external reality, and it is through these contacts that we eventually acquire even abstract ideas." (Montessori, 1966). There are several timely and important questions related to meshing embodiment with mediated educational content. Computer simulations have a long track record now of increasing the learning of content. Rutten et al., (2012) writes, "In most cases simulation conditions showed improved learning outcomes, with effect sizes up to 1.54." Interactive games and simulations of science phenomena are increasingly being used to supplement education, designers need to know how to create optimal interactive content.

In our lab we often ask, how can we harness the affordances of virtual and mixed reality to create embodied, constructivist content? As discussed in Schneider's chapter, best pedagogical practices may depend on the amount and type of embodiment in a lesson. But, how do we determine just how "embodied" an educational simulation is? Without some sort of ranking or categorizational schema, it is impossible to run experimental studies on the efficacy of embodiment and mediated education. The technology is moving rapidly and our theories and design principles need to keep pace. Early work on a taxonomies for VR and user interfaces run the gamut from the technical (Coomans & Timmermans, 1997) to the philosophical (Biocca, 1997). More recently, Lindgren and Johnson-Glenberg proposed six precepts for designing embodied content in mixed reality spaces (Lindgren & Johnson-Glenberg, 2013). The field would benefit from a taxonomy that codified embodiment in educational content, to that end, this section reviews embodiment and concludes with a proposed taxonomy on embodiment in education.

11.1.1 Embodied Learning

Human cognition is deeply rooted in the body's interactions with its physical environment (Glenberg & Kaschak, 2002; Wilson, 2003), as discussed in Slater's chapter. Multiple research areas now support the tenet that embodiment is a powerful underpinning of cognition. The various domains include (but are not limited to): cognitive psychology (Barsalou, 2008; Glenberg, 2008), social psychology (Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005), linguistics (Lakoff & Johnson, 1980), mathematics (Lakoff & Nunez, 2000), gesture - as it relates to learning and language (Goldin-Meadow, 2009; Hostetter & Alibali, 2008), gesture and math (Nathan et al., 2014); theater (Noice & Noice, 2006), and even using dance to learn computer programming (Parmar et al., 2016).

As the above list suggests, theories of embodied cognition have implications for a wide range of human activities and mental processes, and thus can be brought to bear on the full spectrum of learning modalities from the refinement of motor skills to cultivating creative expression to socio-emotional learning. An intriguing demonstration of how cognition is intertwined with the actions of the body is found in an fMRI study where participants listened to words related to various body areas ("lick", "pick", and "kick") and brain activation was observed in the sensorimotor areas associated with performing those actions (Hauk, Johnsrude, & Pulvermüller, 2004). For example, reading "lick" activated motor and premotor areas associated with the face and tongue, suggesting that sensori-motor areas are still important and activated in the adult brain during language comprehension.

Also relevant are studies showing a direct effect of physical enactment on cognitive processes. In the Self Performed Tasks (SPT) domain, Engelkamp and colleagues compared participants who heard a list of unrelated action phrases with participants who performed the actions. The consistent finding was that the self-performing participants recalled more of the phrases than those who merely heard the phrases (Engelkamp & Zimmer, 1994). There is increasing evidence that body movement such as gesture can serve as a "cross-modal prime" to facilitate the retrieval of mental or lexical items (Hostetter & Alibali, 2008). If physical movement *primes* mental constructs such as language, then perhaps increasing an individual's repertoire of conceptually-grounded physical movements will provide fertile ground for new knowledge structures to be developed.

It is on this premise, that adding a motor signal or trace will enhance learning, that our view of embodied education is based. Much of the educational content in western education is instructed using abstract symbols, namely the symbols of language (words and syntax) and the symbols of mathematics. For these symbols to be meaningful to learners they must be based in something outside of the system of symbols themselves. Body perception and action, and experiences based on perception and action, what Barsalou's (2008) calls "perceptual symbols" provide a mechanism for this grounding. It may be the case that when the appropriate sensorimotor systems are engaged via action, then the converging inputs can create stronger and more stable memory traces and learning is enhanced and retained for longer.

Our lab focuses on using representational gestures, these are either captured with external sensors, or with hand controls linked to the newest HMD's (e.g., *HTC VIVE*, Oculus *TOUCH*). But, there are also immersive realms of movement that can be explored with Tangible User Interactions (TUI). Schneider (Chap. 12) describes work using blocks that can be tracked with QR codes. The blocks can now represent any manipulable content and physically moving these blocks encourages learners to be strategic. We would consider these to be meaningful gestures as well and to prime spatial cognition, among other constructs.

11.1.2 The Taxonomy for Education in Embodiment

> In some ways, the body is a primordial display device, a kind of internal mental simulator (Biocca, 1997).

One of the driving goals of the author's lab is to create educational content that meshes the affordances of virtual and mixed reality technologies with best pedagogical practices to result in optimal learning. Educational content is never simply embodied or not, there are probably degrees. Reading a text-only passage that is visually evocative is embodied, albeit we would deem that experience as low embodied. If perceptual symbols are always activated (Barsalou, 1999), then it is problematic to state that some content evokes zero embodiment. As a field, we need more methodical descriptors for the levels of embodiment in lessons.

To this end, a taxonomy with four degrees of embodiment for new media has been proposed following a mathematical "weak ordering" system (Johnson-Glenberg, Birchfield, Koziupa, & Tolentino, 2014a; Johnson-Glenberg, Megowan-Romanowicz, Birchfield, & Savio-Ramos, 2016). The degrees depend on three constructs that are not strictly orthogonal. These are: (a) amount of sensori-motor engagement, (b) how congruent the gestures are to the content to be learned, and (c) amount of immersion experienced by the user. The first two constructs are not unrelated, because for a gesture to be congruent, there must be some amount of sensori-motor engagement. Nonetheless, within these constructs magnitudes can vary affecting the overall degree.

In the Taxonomy for Embodied Education, the continuous spectrum of embodiment is binned into four degrees with the 4th being the highest. The anchor points of the 4th degree, high in all constructs, and the 1st degree, low in all constructs are well justified. The taxonomy represents an improvement beyond the simplistic claim that educational content is either embodied or not.

The embodied degrees and some examples are explicated below.

4th degree = All three constructs are rated as being high. (1) Sensorimotor engagement—A technological platform is available that can map (e.g., via motion capture, etc.) the whole body, or multiple limbs. Therefore the body can act as the controller and action on the display surface is linked to the users' actions. If locomotion is included then visual parallax is also engaged and this is important (Campos et al., 2000) as it further increases sensori-motor activation. Multimodal effects (e.g., auditory and haptic cues) are present and these increase sensorimotor activation. (2) Gestural congruency—Within a lesson there are **multiple** instances of gestures that drive the system, and those gestures are consistently designed to map to the content being learned, e.g., spinning the arm makes a virtual gear spin the same speed and same direction on the screen. This is congruent to and aids in the learning of the educational goal. (3) Sense of immersion—This is a multi-componential construct. Even the authors in this book use the term differently and we have agreed to define the term where it differs from the reference in the introductory chapter. In our lab, immersion is defined as the interactional outcome of three components. First, the field of vision (FOV) that is covered; second, how *engaging* the content this (this includes emotional engagement as well); and third, the degree to which the user loses awareness of the real world (others use the word *presence*). Slater (chapter in this book) and others have published extensively on immersion and presence (Slater, Spanlang, & Corominas, 2010a; Slater & Wilbur, 1997), and several measures of immersion have been developed. In Slater's lab immersion is a property of the system, and he reserves the term presence for the human experience. We conflate the two terms for ease of expression, and because presence and immersion are often non-orthogonal. In one of our studies in this chapter, we further simplify immersion by operationalizing it with only the first component of FOV. Display areas vary from smart phones screens to wrap-around 360° Head Mounted Displays (HMDs) used in virtual reality. Displays that do not have borders in the field of vision are considered higher in the immersion construct.

3rd degree = (1) Sensorimotor engagement—The whole body could be used as the controller, but the user remains in one place (e.g., standing at an Interactive Whiteboard). At least one large physical gesture (beyond finger movement) should be present and linked to the content. (2) Gestural congruency—The system should **contain one or more instances** a gesture that is well-mapped to the content. (3) Sense of immersion—A large screen display or floor projection should induce the learner to perceive the environment as immersive; however, borders are usually present on the periphery.

2nd degree = (1) Sensorimotor engagement—Learner is generally seated, but there is some upper body movement of the arm or fingers. (2) Gestural congruency—this is probably not a defining construct in the lesson, although there is always some interactivity (e.g., a finger swipe to advance, or a flick-wrist-forward action while holding a smart phone to simulate casting a fishing reel), (3) Sense of immersion—The display covers less than 50% of the field of vision; borders and real world are always present no matter the fixation point (e.g., a 16 in. monitor, or tablet-sized screen).

1st degree = (1) Sensorimotor engagement—Learner is generally seated, there is some upper body movement, but usually just for a key press. The learner is primarily *observing* a video/simulation. (2) Gestural congruency—Low. There is no learning-related mapping between gesture and content, the users' movements are elicited primarily for navigation (e.g., tap for next screen). (3) Sense of immersion—Low. The display covers far less than 50% of FOV and borders/real world are always present.

The taxonomy results in eight configurations for the four degrees. Table 11.1 lists the degrees and magnitude of the three constructs binned into low and high. There are two configurations in the 2nd and 3rd degrees that would be odd to consciously create, but they are nonetheless possible, so they are included for symmetry's sake. Why design in a large movement, e.g., a jumping jack, and have it map to a lesson that has nothing in common with the action, i.e., make the first gear in a gear train spin to the right?

Table 11.1 Construct magnitude within degrees in the Embodied Education Taxonomy; *H* High, *L* Low

Degree	4th	3rd	3rd	3rd	2nd	2nd	2nd	1st
Embodiment construct								
Sensorimotor	H	H	**H**	L	L	L	**H**	L
Gestural congruency	H	H	**L**	H	L	H	**L**	L
Immersion	H	L	H	H	H	L	L	L

Cells in Bold It would be odd to require a large movement that was poorly mapped to the content to be learned

11.1.3 Construct 1—Sensori-Motor Activity

Being Active

It appears that doing the action helps people to learn. Recent work with younger learners suggests there are neural differences when children are active versus passive during a learning experience. When 5- to 6-year-old children actively manipulated an object while hearing a new label and then heard the label again, motor areas of their brains were more likely to be activated upon subsequent viewing compared with when they were only allowed to passively watch an experimenter manipulate the named object (James & Swain, 2011). A compelling example of passive versus active science learning comes from Kontra's lab (Kontra, Lyons, Fischer, & Beilock, 2015). Participants who physically held two bicycle wheels spinning on an axle learned more about angular momentum compared to those who observed a partner holding the wheels. Kontra et al. then used fMRI to reveal that the action group did better than the observe group on knowledge tests, and that the level of the BOLD signal in the brain motor regions of interest (left M1/S1) *significantly predicted* test performance for both groups. They tout this as a model that explains how physical experience, relative to observation, increases "activation of the sensorimotor systems important for representing dynamic physical concepts." (p. 6).

If Goldin-Meadow et al.'s postulation is correct that gesturing helps to off-load cognition (Goldin-Meadow, 2011) and free up resources for learning, then perhaps educational designers should consider methods of teaching science content that make use of motoric components and gestures. If gestures help to free cognitive resources, then we should see gains in learning when content is difficult and participants are encouraged to gesture during encoding.

11.1.4 Construct 2—Gestural Congruency

STEM (Science, Technology, Engineering, and Math) topics may benefit from being taught in an embodied manner using new media because many of the concepts are abstract and difficult to grasp. However, the gestures need to be designed to be congruent to the task learned (Kang & Tversky, 2016; Segal, 2011). Congruent means that there is overlap between the representational gesture and the construct being learned. Koch et al., (2011) report that participants react faster in a Stroop condition using congruent gestures (up movement attached to word "happy") compared to incongruent gestures (down movement for "happy") using a large physical 28 in. slider (Koch, Glawe, & Holt, 2011). Glenberg and Kaschak (2002) explore embodiment by varying the direction of button pushes to signal sentence comprehension. They found that participants take longer to react when there is a mismatch between the sentence meaning ('close the drawer') and the button push direction ('towards your body').

Antle and others call these “body metaphors”; her Sound Maker mixed reality system (Antle, Corness, & Droumeva, 2009) uses viable physical mappings for volume, tempo, pitch and rhythm. For example, tempo was associated with speed of movement through the room, pitch was associated with movement up and down in 3D space. She counsels for “interactional mappings that preserve structural isomorphisms between lived experience and the target domain”, what we call congruency.

As an example in the science education and mixed reality domain, middle school students move their bodies along a hypothesized asteroid trajectory (Lindgren, Tscholl, Wang, & Johnson, 2016) to learn about gravity. They walk quickly through the body-mapping platform as they are laser scanned and their movements control a virtual asteroid. Participants who were in the embodied condition, i.e., the whole-body congruent activity, showed significant learning gains, higher levels of engagement, and more positive attitudes towards science than the control group whose movements were not mapped.

11.1.5 Construct 3—Immersion

The third construct is immersion. Coomans and Timmerman (1997) state that immersion is “…the feeling of being deeply engaged… (in) a make believe world as if it was real.” (p. 279). Immersion is a term somewhat in flux in America and needs to further operationalization for education. Coulter and colleagues (2007) showed that students who learned how to treat a head trauma victim via a proprietary virtual HMD (which they deemed the “full immersion” condition) showed significantly better learning than students who learned on a laptop monitor (deemed the “partial immersion” condition). In the paper, it is not explained why those condition definitions were chosen. A meta-analysis by Miller and Bugnariu (2016) showed that for high-immersion virtual environments, treatment response was overwhelmingly positive for those with autism spectrum disorder who were learning social skills. However, in a small n correlational study run by Bailenson’s group (2012), participants who learned multiple environmental messages while in a VR shower recalled less content. Participants filled out a five item Physical Presence questionnaire and those with higher presence scores, recalled less content on a cued recall task. This significant negative correlation had not been predicted, and the authors speculate that after a highly vivid sensory experience, participants may have had limited cognitive resources left over to dedicate to the memory task. Thus, the idea that an immersive environment will indiscriminately enhance learning has not been fully supported. We do not know if the study included many high gestural congruency mappings to the eco-messages to be remembered. The issue of seductive details may take on more importance as environments become more immersive. For education, less may be more.

When immersion, as it relates to learning, is rigorously operationalized we will be better able to weave it into our content and assess its unique effects on learning. The most thoughtful definition so far, using the system level analysis, comes from

Slater and Wilbur (1997). The immersive capability of an environment depends on the following five components: *inclusive*, *extensive*, *surrounding*, *vivid*, and *matching* (Slater & Wilbur, 1997). *Inclusive* refers to whether signals pertaining to the physical world have been eliminated (e.g., joystick, weight of wearables, etc.). *Extensive* refers to the number of sensory modalities that are part of the experience. *Surrounding* refers to the visual presentation including field of vision (FOV) and the degree to which the physical world is shut out. *Vivid* refers to the fidelity and resolution of the simulation. *Matching* refers to whether the viewpoint of the environment is modified to match the user's perspective (e.g., in an HMD when the user moves left, the environment moves as well). Issues associated with vividness and matching have been mitigated the past several years. The majority of researchers use surveys but we also note that physiomarkers have been used (i.e., heart rate, skin conductance, pupil dilation, etc.). As an example of a bio-marker, Slater et al. (2010b) use heart rate deceleration and show that deceleration significantly correlates with key emotional experiences reported on a post evaluation survey. Immersion is complex, and may not be well-measured by one metric because it is not one dimensional. At any point users may feel present in "… one of three places: the physical environment, the virtual environment, or the imaginal environment… Presence oscillates among these three poles", Biocca (1997).

In the next two sections, two studies are described that controlled for amount of embodiment (which includes the construct of immersion). In the first, a virtual learning environment is used, and in the second, a mixed reality environment is used. The chapter ends with several best practices for design.

11.2 Virtual Learning Environment Study

11.2.1 Electric Field—Embodiment of Abstract Content

It has become increasingly cost effective to use sensors like the Microsoft *Kinect* to map movements and then drive simulations with users' body actions. As designers, we want to understand how adding gestures and movement affect science learning. We make the comparison in this study between a low embodied condition—watching science simulations on a larger projection surface—to a high embodied condition where learners use gestures to actively construct models on the same sized projection surface. We varied the amount of embodied content, the amount of active generation of the gestures, and whether there was a narrative story line that held together the seven simulations. We do not address the null results of the narrative condition here, but those results can be read elsewhere (Johnson-Glenberg & Megowan-Romanowicz, 2017).

The study was a between subjects 2 $\times$ 4 design. The first factor was time with a pretest and immediate posttest; the second factor was condition with four levels described in more depth below. In addition, two types of tests were administered, the first was a more verbal assessment that used a keyboard for input, and the second was an innovative gesture-based assessment, called the Ges-Test, that we hypothesized would be more sensitive to revealing learning gains in the embodied conditions. All participants were exposed to the same learning "text cards", written in a low embodied expository style (no anthropomorphization or highly evocative language).

The Manipulated Conditions.

1) *Symbols and Text (S&T)*—In between the text card sections, the control S&T group answered quiz questions that included *only text and symbols* for equations and questions. Participants read the short multiple choice text-only questions that appeared after each content section. After each text section there were four multiple choice questions designed to reinforce what had just been read and to equate for time between conditions. Thus, no graphics nor simulations were seen or acted upon between sections.
2) *Low Embodied*—In the Low Embodied condition, participants watched animations or simulations that were pre-created (similar to viewing a video). The participants could start the animations but they did not actively control the action within the animations.
3) *High Embodied*—The final two conditions (3 & 4) are called High Embodied. In condition 3, the Microsoft *Kinect* sensor mapped key body joints and motion. After the instructional text sections, participants were able to physically interact with the seven simulations. As an example, in the simulation called *Scuff-n-Spark* participants would actually scuff their feet up and down a section of carpet and "pick up electrons". The rate that participants moved their knees drove the simulation on screen. The more electrons they accumulated, the more blue dots showed up the bottom of the screen in the Scuffometer (see Fig. 11.1) and the higher the q_{Net} on the virtual hand rose. When participants decided the q_{Net} was high enough they could reach forward with their real hand and the virtual hand on-screen would move toward the door knob and result in a spark. The dynamic relationship of Coulomb's Law stayed on screen (upper left corner). Bodily actions altered the size of the symbols in the equation in real-time (e.g., q_1 was mapped to the charge build-up of negative electrons). This is a powerful instance of embodiment *with* symbols and instantiates representational fluency.
4) *High-EMB-Narrative*—The 4th condition was the same as the 3rd except that seven graphic narrative cut scenes were inserted before the simulations. A cut scene is a comic-style graphic with text bubbles that appeared and faded.

Videos and games can be downloaded at https://www.embodied-games.com/games/all/electric-fields or https://www.youtube.com/watch?v=eap7vQbMbWQ.

Fig. 11.1 The *Scuff-o-meter* screen shot with the dynamic equation in the *upper left* corner

11.2.2 Embodied Assessments

Two assessments were administered at pretest and posttest, they were invariant. First, a content knowledge pretest was taken on a computer. This was a more traditional non-gesture based assessment using the keyboard as the input device. Second, the Ges-test was taken on the *Wacom*™ *Intuous Pro* (15.1 in. or 38.4 cm active diagonal). All participants confirmed they had never used a *Wacom* before. This is essentially a large tracking pad with high accuracy for touch. The *Wacom* was placed on the table beneath the 16 in. diagonal testing computer monitor. To keep the assessment as haptic and embodied as possible the stylus was not used, instead participants drew with a fingertip on the *Wacom* surface.

The mechanic was a double tap that would signal 'start tracking' and a drag across the screen would result in a line or vector onscreen. Figure 11.2 shows a student who drew towards the right and slowed down with time. As the finger moved across the *Wacom*, users saw a colored line trailing behind a larger circle that represented the touch. Every 100 ms white dots were placed inside the colored line.

The placement of the white dots is a visual cue for speed, similar to the motion map concept used in Modeling Instruction (Hestenes, 1987). Users should be able to *feel* if they are accelerating, but the visual feedback of the white dots as a motion map also allowed users to *see* that when the finger moves faster the dots spread further apart. The dots get closer together as the user is slowing down before stopping on the far right.

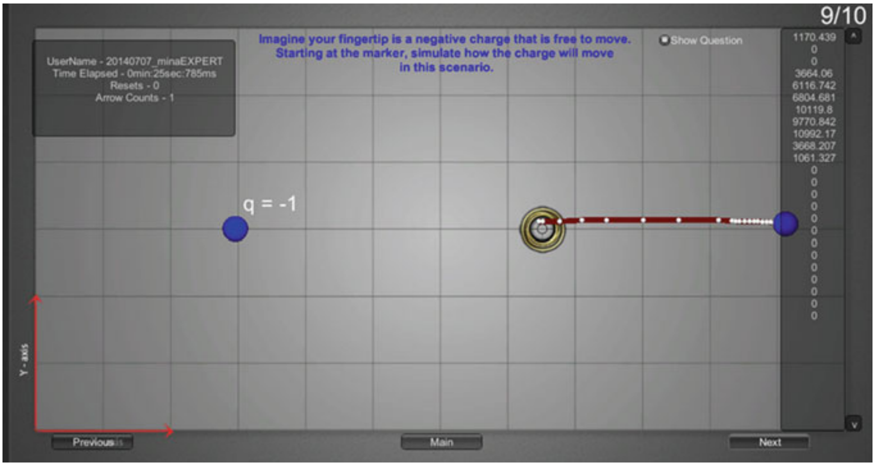

Fig. 11.2 Screenshot of the *Wacom* Ges-Test, the finger is used to draw charge movements and vectors. The *white dots* represent finger location similar to a motion map

11.2.3 Results for Electric Field Study

Participants (N = 134) were randomly assigned to condition. We are interested in the difference between the average of group 1 and 2 compared to groups 3 and 4. That is, the split between the low embodied groups and the two high embodied active groups. All four groups were equated on the Ges-Test at pretest. A linear regression analysis revealed a significant active embodiment effect on the Ges-Test, $F_{(1,\ 132)} = 3.77$, $p < 0.05$. The low embodied groups gained 2.03 (SD 7.03) and the high embodied groups gained 4.79 (SD 8.36), for a moderate Effect Size (Cohen's *d*) of 0.35.

Interestingly, the traditional keyboard-based knowledge test did not reveal a low versus high embodied effect. The traditional keyboard test revealed only that the three embodied groups (i.e., the low embodied, high embodied and high embodied + narrative) performed significantly better than the control symbols and text group, $F_{(1,\ 164)} = 4.23$, $p < 0.04$, Effect Size (Cohen's d) = 0.38.

11.2.4 Conclusions for Electric Field

With motion capture technology becoming more cost effective and entering education, and virtual/mixed realities meshing with the embodiment that motion capture enables, it is more timely than ever for researchers and educational content designers to use a codified language. As a field, we are in need of studies that explicate the most efficacious components in embodied science lessons, and we need a method for discussing the degrees of embodiment. For the four conditions in this study, the conditions map to the degrees in the following manner: Control, symbols and text = 1st, the low embodied condition (observe simulations) = 2nd, the high embodied and high embodied/narrative (gestures construct simulations) conditions = 4th. The study above highlights that being active and embodied benefits learning, in addition, we must also be creative about the type of metrics to assess learning.

New immersive media need more procedural and embodied assessment measures. The chapter by Shute (Chap. 5) describes creative methods for assessing learning during gameplay and active simulations. For the electric field study, a new gesture-based metric was designed and it proved to be more sensitive to the learning gains associated with motion and vectors. When knowledge was assessed via the larger tablet format that facilitated gestures, the two active high embodied groups scored significantly higher on knowledge gains. This suggests that more sensitive and embodied metrics should be developed that also assess knowledge that is gained in a more embodied manner.

11.3 Second Example Study—Mixed Reality with *SMALLab*

The second study compares a mixed reality environment with two of the more common learning platforms found in schools. The six counterbalanced lessons were designed to be either high or low in embodiment and to maximize the affordances of each platform. A full description of this study can be found in (Johnson-Glenberg et al., 2016) in *Frontiers in Psychology*. To ask the question of how learning gains are affected by platform crossed with embodiment, three different platforms were selected. The first was *SMALLab* which stands for Situated Multimedia Arts Learning Lab. With an overhead projector, one dozen *Optitrack* motion-capture infrared cameras, and a very large projected floor display (21 foot or 252-in. diagonal) a highly immersive learning platform was created. Figure 11.3 shows a learner surrounded by the graphical "motion map" feedback she created during the centripetal force lesson.

All lessons also included auditory feedback, the pitch increased as speed increased on the tethered objects. The second condition used the *Promethean* ActivBoard, an Interactive Whiteboard (IWB-78 in. diagonal) as the learning platform. The third condition used a traditional desktop computer with a monitor and mouse set-up (16 in. diagonal). The hypothesis was that the high embodied, 4th degree *SMALLab* platform which encouraged larger sensori-motor activation (participants could physically spin objects and locomote) and included a greater sense of immersion (defined by FOV) would result in better learning and greater delayed learning gains.

Fig. 11.3 *SMALLab* interface with learner in Centripetal Force simulation

While designing the pedagogy of the lessons, we were careful to use instances of implicit scaffolding to introduce each component of the centripetal force equation ($F_C = mv^2/r$) to the learners. This is also a technique advocated by the designers of the PhET simulations (Johnson-Glenberg et al., 2014c). In addition, interface components were added one step at a time after the learner demonstrated mastery. E.g., each bar graph (first speed, then force) was introduced alone and participants had to verbalize the purpose of the component before the experimenter added another.

One of the greatest differences between the low and high embodied conditions in this study was that we varied gestural congruency. In the high embodied condition, *SMALLab* participants swung a tethered bob overhead and they could *feel* centripetal force as it acted on the arm and body; this provided a sense of authenticity, as discussed in Jacobson's Chap. 3. This is highly congruent to the concept to be learned, i.e., velocity is directly proportional the amount of centripetal force. In the low embodied conditions, the virtual bob that was spun was not "well mapped" because a horizontal slider was used to increase or decrease the speed of the bob. Again, in the high embodied conditions, the physical act of spinning the bob overhead or using an interactive tracking pen on the IWB, or spinning the mouse in the desktop condition would be considered high embodied because it *corresponded directly to and drove* the speed of the virtual bob. In juxtaposition, in the low embodied conditions, the speed of the bob was driven by lateral placement of a virtual slider—left for slower, to the right for faster. To see a video to help conceptualize, please visit www.embodied-games.com/games/all/centripetal-force or https://www.youtube.com/watch?v=oFiXtcXRpVE.

Tangibles constructed for the MR platform. One of the exciting aspects of working in mixed reality environments is that it is possible to construct manipulables that interface between physical gesture and the virtual displays. For the *SMALLab* high embodied condition, two new manipulables were constructed. The "swinger" had two components: a plastic handle that connected to string and in the end was a tracked ball (the bob) in which mass could vary. The "flinger" was a dually tracked manipulable that was used to assess the learning of trajectory at point of release. (A common misconception that many novices believe is that an object released from circular motion will continue to travel on a circular path, this is called the impetus misconception.) The flinger is shown in Fig. 11.4. The brass lever on the top of the handle serves as the release mechanism.

Participants physically spun their entire bodies around in a circle holding the flinger in front. They then released the bob at a time of their choosing to hit a target on the floor. That is, the large tennis ball (the 'bob' part) of the unit would disengage when the brass lever was pressed, and the ball would fly from the tracked handle. The smaller tracked spheres on both components are covered with retro-reflective tape and this allows the IR cameras to map the positions of both the handle *and* the moving bob. Participants are able to observe how the bob flies at the point of release. They begin to address the impetus misconception regarding trajectory at point of release. See Fig. 11.1 for an image of the learner who missed the target, but sees the mediated feedback on the floor projection regarding the path

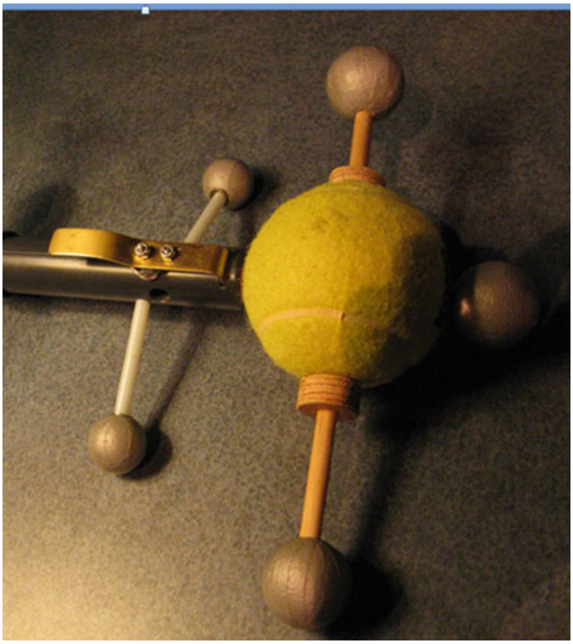

Fig. 11.4 "The Flinger" constructed for *SMALLab*, the smaller spheres are mapped in realtime by the 12 IR cameras in the ceiling

after release. The bob flew in a straight line (the curled line represents the hand-held part that continued to spin with the participant). This is another fine instance of representational fluency.

Low embodied conditions. In the low embodied *SMALLab* condition, participants used a different rigid-body trackable object. This was an extant 3D-printed manipulable/wand. Participants in this condition used the wand to control the virtual slider projected on the floor and to signal the release from spin via raising the wand in the Z axis. In all three low embodied conditions (including the IWB and desktop), the participant controlled speed of spin with a horizontal virtual slider.

11.3.1 *Results* SMALLab *and Centripetal Force*

The 109 college-age participants were randomly assigned to one of six 50 min-long lessons. These experimental conditions were derived from two factors. The first factor, amount of embodiment had two levels: (1) low and (2) high and the second factor of platform had three levels: (1) a mixed reality immersive environment *SMALLab*, (2) an interactive whiteboard system, and (3) a mouse-driven desktop computer. The levels were crossed resulting in six lessons. Pretests, posttests, and one-week followup (retention) tests were administered resulting in a $2 \times 3 \times 3$ design. In this study we also gave two different types of knowledge subtests, one that relied on more declarative knowledge and was administered on a keyboard. The second subtest relied on more generative and gesture-based knowledge, e.g., hand-drawing vectors.

Regardless of experimental condition, ALL participants made significant immediate learning gains from pretest to posttest, $F_{(1,\ 99)} = 459.89$, $p < 0.001$. There were no significant main effects or interactions due to platform or embodiment on immediate learning. One week after posttest, 63% of participants returned and took both subtests again. From posttest to followup the level of embodiment interacted significantly with time, such that participants in the high embodiment conditions performed better on the subtest devoted to generative knowledge questions. On the generative subtest only, there was a significant interaction between level of embodiment and posttest to follow-up (i.e., delayed learning gains), $F_{(1,\ 62)} = 4.83$, $p < 0.03$. Platform was not predictive of either immediate or retention scores.

11.3.2 *Conclusions for Centripetal Force*

We posit that better retention of certain types of knowledge can be seen over time when more embodiment is present during the encoding phase. This sort of retention may not appear on more traditional factual/declarative tests.

The retention effect was only seen on the test that was more sensitive to embodiment, i.e., the generative test where participants had to draw vectors to show the path at the point of release. Some readers might consider all three of these platforms to be virtual reality, including the one on the typical computer monitor, but we would call that a virtual environment and not virtual reality. Using the definition in Chap. 1 (this book), only *SMALLab*, the mixed reality space with the large FOV approached virtual reality. The fact that all conditions made immediate significant learning gains demonstrates that all six were well designed lessons, even the low embodied ones. In addition, a decision was made that we did not want students to leave the study with incorrect mental models. Thus, when participants answered a prompt incorrectly (e.g., replying that "a *longer* string would result in *more* centripetal force"), participants were asked to run through the task again and to answer the question again. If they made the same incorrect conclusion three times in a row, the experimenter explicitly supplied the correct answer. This corrective guidance assured that the knowledge needed to show competency on the posttest was voiced at least one time. It is still worth noting that no one scored 100% on the posttest.

The conditions differed primarily in the amount of kinesthetics and gestural congruency. Cook, Mitchell, & Goldin-Meadow (2008) report that "gesturing makes learning last" in the domain of learning a new mathematical concept. We saw that the condition with the most gesturing and movement via whole body (high embodied *SMALLab*) was indeed the condition in which the learning persevered more robustly. This may be due to the multiple instances of gestural congruency during encoding and because the high embodied condition elicited more sensorimotor activity. A greater amount of physical movement should activate complex motor neuron patterns and these will be associated with the learning signal. In addition, motor planning recruits resources that have downstream effects that may affect delayed learning gains. The delayed retention was significantly different between embodied conditions. We have seen similar delayed results on nutrition knowledge tests when comparing low and high embodied learning conditions in an exergame (Johnson-Glenberg, Savio-Ramos, & Henry).

Take Home Message

The take home message from the two studies is that mediated immersive content is a powerful instructional tool and that each delivery platform comes with its own set of affordances. Ultimately, what is done with the affordances and the amount of embodiment included in the lesson may prove to be the strongest predictors of learning gains and may affect the magnitude of the content retained. The new handheld controllers with commercial VR packages will make it much easier to design representional gestures into lessons. It is crucial that the educational design communities begin to understand and then disseminate principles for design.

11.4 Principles of Design

The chapter ends with a set of design principles that has been gathered and refined over the 25 years that the author has been designing educational content and assessment measures. Other chapters in this book describe good and poor uses for virtual reality (e.g., see Jacobson, Chap. 3). This list begins with content design principles and then moves on to some guidance for assessment measures:

Be creative with affordances of the technology—For the centripetal force study, we chose three very different platforms and then spent multiple months brainstorming how to maximize embodiment in each one. The sessions designing for the high embodied mixed reality *SMALLab* condition were especially creative and engaging because all virtual and physical phenomena were "on the table". We practiced physically running around poles with ropes tied to our waists ("you be the bob!"). We ran in circles with backpacks filled with rocks to increase mass. In the end, we chose to mimic the classic force concept test item from the CFI inventory and used the model of spinning a tethered object overhead. Next we had to design for swinging/spinning motions for the whiteboard which was a vertical surface; here we were able to engage the shoulder and arm with representational gestures. Finally, we designed for the horizontal, mouse-driven interface of the desktop. Spinning the mouse in a circle on the table best approximated the agency used in the other spin tasks. For each platform the team worked to maximize the amount of sensori-motor output that could mapped to gesturally congruent movements.

Being embodied and active—The user should move. The amount of sensori-motor activation is hypothesized to be predictive of whether the content is highly embodied or not. A greater amount of physical movement should activate complex motor neuron patterns and these will be associated with the learning signal. Cook, Mitchell, and Goldin-Meadow (2008) hypothesize that the significant delay test results seen in their gesture and gesture/speech groups may be because, "…expressing information in gesture may produce stronger and more robust memory traces than expressing information in speech because of the larger motor movement". We are now designing for HMD's that use wireless hand controls, and believe it is important that meaningful hand gestures be part of the lesson. At the same time, being in a fully enclosed HMD experience, where the real world is not viewed, can be dangerous and disorienting and does not lend itself to sustained locomotion. The cost of adding synchronized co-location to HMD experiences will continue to drop, but for the next several years it will still be expensive to get multiple live players in a VR space. If face to face discourse is one of your goals, you may want to spend more time in the AR and Mixed reality worlds.

It is not necessary to install an expensive CAVE to be able to move the entire body and openly discourse with others in sightline. *Pokemon Go* is an augmented example that encourages locomotion on a ubiquitous device. Klopfer (Chap. 10) has been a leader in designing for augmented education.

When designing activity into learning games, we have often used a regular projector and the inexpensive *Kinect* sensor. For example, *Alien Health* is a co-located, dyadic nutrition instruction game that incorporates gesture and virtual reality components. In the game, players would swipe healthy food choices into an alien avatar's mouth. The hypothesis was that the embodied gesture primed the action of choosing and eating healthier foods in a forced choice task. Players were then prompted to perform several exercises to "help the alien metabolize the foods" (Johnson-Glenberg et al., 2014c). Participants in the exercise condition performed better on a post intervention nutrition test. Again, our research suggests that the platform is not what is critical, more important may be the amount of embodiment in the lesson.

You may be forced to design for a platform becoming more popular in schools, e.g., the tablet. How might you make that lesson more embodied? If you were teaching centripetal force, perhaps users could hold the tablet in outstretched arms and spin while the accelerometer provided feedback. That would be engaging! On the other hand, the tablet could easily be dropped. A safer design might be to allow the user to spin a virtual bob around with the fingertip on a touch surface. That is active, gesturally congruent, and gives the user agency.

Give a sense of agency—Giving a learner "agency" is a direct consequence of allowing them to be more active. Agency in the social sciences means that someone has taken a deliberate action and that forethought was involved. In the mediated education domain, we extend the definition to mean that the learner controls what happens on the display device, which in turn affects the feedback received and future choices. Choices and the activity on screen are not all pre-programmed and preconceived, i.e., similar to watching a video. As an example, in *Scuff'n'Spark*, the learners are in control of how many electrons accumulate on screen because they control the rate at which they lift their knees. Agency, like embodiment, probably comes in degrees.

One of the highest degrees of agency would surely be when users can set the start state for a simulation with parameters of their own choosing. Creating a system that accepts user-created content is not trivial. A guided user interface (GUI) must be embedded in the system. That always costs extra funds, but it may well be worth the expense. As an example, in the gears game referenced earlier, an interface was created where students and teachers could enter their own coordinates to build a series of hill heights (slopes) that their peers would then race up on the multi-geared virtual bicycles (Johnson-Glenberg, Birchfield, Megowan-Romanowicz, & Snow, 2015). It was a powerful method for combining the construct of physical effort (spinning the arm around the shoulder to move the virtual bike) and instantiating the concept of mechanical advantage with gear diameters. See Fig. 11.5 with a dyad playing the *Kinect*-driven game called *Tour de Force*. The player with the top bike is ascending a hill with a steeper slope: https://www.youtube.com/watch?v=kSsiJZOUKt4.

Be congruent—When picking the representational gesture that will give the learner agency over the content, think through how congruent the movement is to the construct to be learned. A hand push forward is not congruent to learning about circular motion. Mapping the arm as it is spun with a certain velocity is congruent. In the biking and gears game in Fig. 11.5, the speed and direction of the arm spin maps directly to the speed and direction of the primary gear turning.

Scaffold components and complexity—As you choose learning objects and their placement-both in the lesson and on screen, be sensitive to the amount of content on display. Giving users control over placement of content can quickly lead to cognitive overload. There is a finite amount of resources learners bring to any multimedia task (Mayer, 2009; Sweller, van Merrienboer, & Paas, 1998). In our embodied world, we also expect the learner to master both the kinesthetic and cognitive requirements of the lesson. The learners must acclimate to a gesture to

Fig. 11.5 The gears *Tour de Force* game, players spin their arms to drive the bicycles up the hills

control content on the display, as well as adroitly integrate new knowledge into their pre-existing knowledge structures. If a learner needs to overturn a misconception or incorrect p-Prim (diSessa, 1988) this will require even more effort. The timing of the components revealed in the lesson must be appropriate to the complexity of the content (while accommodating varying levels of prior knowledge). In both experiments described, we were careful to slowly build on foundational knowledge. The electric field series begins with a simulation to count the number of electrons in an atom, moves on to vectors and sparks, and ends with the final game on a lightning strike. The important point is that when learners are in augmented or virtual environments there are many components vying for attention (Dunleavy & Dede, 2014; Squire & Klopfer, 2007; Wu, Lee, Chang, & Liang, 2013). We need to design sensitively and that may mean stripping down the interface for the first few lessons, or beginning with lower level content as a refresher before revealing the novel content. As Abrahamson and Lindgren (2014) advise, the "action-environment couplings should be gradually introduced".

Encourage collaborative interaction—The education field does not yet have a cost-effective platform for allowing multiple users to interact in realtime via HMDs, that day will come though. Until then, we continue to focus on some of the unique affordances of augmented devices that allow learners to be very collaborative. Social aspects are important in immersion as discussed in Kraemer's chapter. One can also use these devices for jigsaw pedagogy and differentiated role play as inquiry-based activities (Dunleavy & Dede, 2014; Squire & Klopfer, 2007); examples are provided in Dede's and in Klopfer's chapters. With handheld devices several learners can huddle around a device and discourse in a natural style. Per Lindgren and Johnson (2014), designers should be striving to make VR and immersive education more collaborative. *SMALLab*'s very large floor projection allows for four learners to be active in the center at once. When *SMALLab* is in a school, the rest of the class (those not being tracked in the center) sit around the perimeter and takes notes, or make predictions, etc. They are kept active and engaged with relevant tasks. There are benefits to co-located mixed reality environments that are not readily apparent with the other platforms.

Be error friendly—Having agency means the learner will also have opportunities to fail. Best to embrace failure. When participants self-constructed and then ran their models in the final two conditions in the electric field study, they were able to get it wrong. When that happened learners received immediate feedback. After two failures, hints were supplied. We speculate there is something special and more salient about learners creating their own errors (compared watching the animated errors in the different condition). Best design practices for creating games often include planning for low stakes failure and when players show they understand a concept, they are then moved up in levels of difficulty and expertise (Gee, 2007).

Design in opportunities for reflection—Please don't forget to put in a place for reflection. We have found ourselves over-designing with bells and whistles and non-stop action. This may keep eyes on the screen, but it is not always optimal for comprehension. We now try to build in space where the learner can pause and reflect on what was learned. A classic technique is to have the learner stop and speak to a peer about how they understand the content, or perhaps learners could be prompted to type up a paragraph on how this new knowledge might relate to their everyday lives.

The Assessment of Learning

Learning gains may show up in unexpected ways—The author comes from a somewhat traditional experimental psychology training and has too often wielded the clunky assessment brush of quantitative assessments. The picture will always remain incomplete if only one type of assessment is used. My best current advice is to assume that learning gains associated with embodied content will appear in unexpected places. The effects may show up as retention effects one week later (Johnson-Glenberg et al., 2016). Perhaps this is because sleep helps to consolidate the two separate verbal and motor signals as delayed gains. What happens to memories during sleep is an on-going area of research (Stickgold & Walker, 2007). The learning gains may *never* appear if the assessment is not sensitive to them. The measure should perhaps query for knowledge in a manner isomorphic to how the knowledge was encoded—called encoding specificity (Tulving & Thomson, 1973). If the goal is to distinguish the learning difference between low and high embodied conditions, then you may need to design an assessment that incorporates representational gestures (similar to our *Wacom* Ges-Test) (Johnson-Glenberg & Megowan-Romanowicz, 2017). Bayesian analyses (Shute, Chap. 5) are well suited to in-process analyses and non-traditional assessments like learner diaries and the studio books used by Shaffer et al. (2009) hold promise.

In-game assessments—We have also experimented with in-game or in–process assessments. The premise is that learning in the game should be designed so that the player cannot move up a level until the current level has been mastered. If a learner is not understanding the concept, as evidenced by in-game decisions, then the learner remains at that level which serves as a proxy to current skill state. For example, in the Alien Health nutrition exer-game (Johnson-Glenberg, et al., 2014c), players must deduce that feeding the alien too much high fat food will make him fall asleep. Players are motivated to learn the rules and move up in levels because it is much more fun to pilot the ship with gestures, than to watch the alien snooze. Players are doomed to repeat the same levels over and over again until they feed the alien the better food choices. We find this to be a more naturalistic way for learners to demonstrate they understand a concept compared to giving them standard, end of the unit surveys or multiple-choice tests that "drop from the sky".

If content is embodied, make assessment match—This has been covered elsewhere, but deserves its own line.

Don't stop at lab studies—This is a point that was made in the Lindgren and Johnson-Glenberg article (2013) called *Emboldened by Embodiment*, and it bears repeating. Many great ideas start in the laboratory. However, for the learning sciences to evolve we need field work. Education should be effective for the masses, and new ideas and technologies should not only be assessed for efficacy in the laboratory. Content delivery and assessment measures need to be tested in the trenches as well. As designers and end-use researchers of content, we find it jarring that so many of the "great ideas" on paper or in our small homogenous-group lab studies do not play out well in the messy field. Nonetheless, we forge ahead, make iterative changes in the designs and teacher prep materials, and the process carries on. This is also a good place to mention that teachers will need specific instructions and training on how to use the emerging immersive VR and MT technologies in their classes. Efforts should be expended to create quality teacher preparation materials.

Above we list some meta-level design principles. Slowly, we see that more fine-grained design principles for VR are beginning to emerge in journals and proceedings, e.g., keep locators on horizon, do not allow too many objects to fly TOWARDS you, be aware if you add a virtual nose or any body parts that skin tone should match the users' (unless your goal is one of altering IAT or empathy—see Slater chapter). It is positive that these tips are being learned and disseminated and it is an exciting time to be in mediated educational technology.

11.5 Conclusions

This chapter attempts to address several timely and important issues related to creating mediated embodied educational content. One important issue is that we need to be using the same language to describe embodiment and we should be more precise regarding the degree of embodiment in an educational scenario. To that end, a taxonomy for embodiment in education has been proposed with four degrees of magnitude based on the presence of three constructs: (a) amount of sensori-motor engagement, (b) how congruent the gestures are to the content to be learned, and (c) amount of immersion experienced by the user.

The chapter ends with eleven principles:

The Creation of the Content

Be embodied, be active
Give a sense of agency
Be gesturally congruent
Scaffold components and complexity
Encourage collaborative interaction
Be error friendly
Design in opportunities for reflection

The assessment of Learning

Be flexible, learning gains may show up in unexpected ways
Embed in-game assessments
If content is embodied, make assessment match
Don't stop at lab studies.

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Chapter 12
Preparing Students for Future Learning with Mixed Reality Interfaces

Bertrand Schneider

Abstract In this chapter, I explore how new learning environments, such as mixed reality interfaces (i.e., interfaces that combine physical and virtual information), can prepare students for future learning. I describe four controlled experiments that I have conducted over the years where students learned complex concepts in STEM and where a Tangible User Interface created a "Time for Telling". This is followed by a summary the findings, a discussion of the possible mechanisms for the effect found in those studies, and a suggestion of design guidelines for creating this type of constructivist activities. I conclude by discussing the potential of mixed reality interfaces for preparing students for future learning.

Keywords Tangible user interfaces · Preparation for future learning Augmented reality

12.1 Introduction

Over the past decades, new advances in Human–Computer Interaction (HCI) have radically changed the way we interact with computers. Technology has become more pervasive, ubiquitous and intuitive to use. The possible inputs are now multi-modal: users can talk, touch, gesture or even use their gaze to control a computer. The output is no longer limited to a screen; Augmented Reality (AR) systems can overlay digital information on the perceived physical world, and Virtual Reality (VR) can immerse users into virtual worlds. The lines between digital and physical worlds have blurred, which dramatically increases the design space for creating new types of immersive learning experiences. The scenarios that students can experience in mixed-reality/virtual worlds are many and can result in

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effective, efficient and engaging learning. They were not possible before the advent and maturation of these powerful digital technologies.

It seems logical to assume that those experiences have an untapped potential in education. It also makes sense that they cannot—and should not—be used to replace all types of instruction. Rather, we would expect those experiences to be used strategically to maximize learning. But what are the theories that could inform when and how those immersive learning experience would benefit learners the most? In this chapter, I explore one possibility by leveraging a framework called Preparing for Future Learning (PFL). The PFL framework suggests that particular kinds of experiences can help students build prior knowledge in specific ways, which will then help them take advantage of subsequent instruction. The focus of this chapter is to enhance those experience through new technologies.

In this chapter, I first introduce new types of computer interfaces that offer interesting potential for education (Natural User Interfaces, and more specifically Tangible User Interfaces) and describe their affordances for learning. In Sect. 12.3, I introduce the PFL framework and its implications for designing learning environments and new pedagogical scenarios. Section 12.4 is a summary of empirical findings that highlight the benefits of adopting this constructivist approach. Finally, I discuss implications of those results for designing innovative learning environments.

12.2 Natural User Interfaces (NUIs)

If we look back at the first computers in the 80s, it is astonishing to think about the steepness of their learning curve. The command line interface (CLI) appeared first, where the keyboard was the only available input. It forced users to memorize complex mapping between keystrokes and actions: for instance, the VI text editor—which is 40 years old, but still used today—required users to press the letter h, j, k, l to move left, down, up, right on the screen, i to insert characters, d to delete them, and so on. Even though VI is still among the most powerful text editors available to programmers today, it still takes a massive amount of time and energy for any given user to gain fluency in its use. The introduction of the graphical user interface (GUI) has allowed users to point at elements on a screen with a mouse, and reduced this learning curve by an order of magnitude. Instead of memorizing complex keystroke sequences, users can merely point and click. Over the past decade, this learning curve has become almost non-existent. Toddlers, for instance, have no issues interacting with touch-screen tablets. The emergence of new kinds of interfaces, called natural user interfaces (NUIs), have transformed the technological landscape. NUIs are defined as “systems for human-computer interaction that the user operates through intuitive actions related to natural, everyday human behavior”. In short, there is no need to learn specific mappings between inputs and outputs on a NUI: the content is the interface (Wigdor & Wixon, 2011). NUIs include touch screens (e.g., the IPad™), gesture-based systems (e.g., the Kinect™

sensor), voice-controlled programs (e.g., Cortana/Siri™), gaze-aware interfaces (e.g., TobiiX™), and brain-machine interfaces that read neural signals and use programs to translate those signals into inputs.

This revolution has dramatically changed the way we interact with computers, and has implications for designing educational activities as well. Designers can create rich scenarios for wider audiences who, for instance, could not use standard interfaces very well—such as very young children, people with physical disabilities as well as individuals who are less comfortable with technology. This also means that we can redirect the burden of learning a computer interface toward more useful cognitive processes. Instead of having students struggle with memorizing mappings and menus, they can focus their energy on the learning task. Finally, it allows instructional designers to create multi-modal interactions. Some domains are best explored through gestures and body movements, while others benefit from collaboratively and verbally exploring a subject. New interfaces (gesture-based, brain-controlled, gaze-aware, voice-controlled, and so on) have particular affordances that could benefit learners in different ways. In this chapter, I focus on one type of NUI that has interesting properties for educational applications: tangible user interfaces.

12.2.1 Tangible User Interfaces (TUIs)

One kind of NUIs that holds interesting potential in education are Tangible User Interfaces (TUIs). TUIs are systems in which users interact with digital information through the physical world. The most common implementation of a TUI is a horizontal interactive tabletop that detects the location and orientation of physical objects (tagged with fiducial markers, which are similar to QR codes), and displays additional information on top of them usually with a projector. They transform traditional manipulatives into dynamic objects that respond to users' actions through an augmented reality layer. Since anything can be displayed on the virtual layer, it allows designers to combine physical and digital affordances in a way that was not possible before. For example, the Reactable (Fig. 12.1, left) is an interactive tabletop created to support creativity through musical exploration. In this environment, each object is associated with a specific musical sound or action (e.g., changing the pitch or volume of a tone). Users can easily connect objects together to create musical compositions in an intuitive and playful way. Another example is the Sandscape system (Fig. 12.1, right), which allows users to design and understand landscapes using sand. The tangible interface then displays various information about the landscape model to show its height, slope, contours, shadows, drainage or other features of the simulation.

From a pure HCI (Human–Computer Interaction) perspective, there are several advantages associated with TUIs. They leverage everyday objects or material with which users are already familiar. This significantly reduces the amount of time necessary to learn the interface. When well designed, users can just jump in and

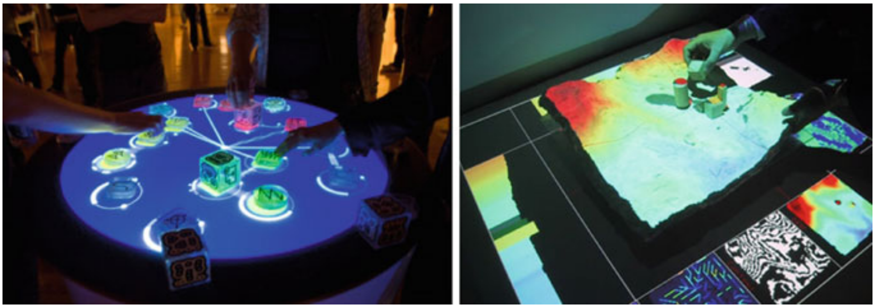

Fig. 12.1 On the *left*, an interactive tabletop for creating music (the Reactable). On the *right*, a landscape created with sand and augmented with a digital information (the Sandscape system)

explore the system on their own without any need for tutorials or explanations because the interface is intuitive and obvious to many users. TUIs also combine the best of the physical and digital world. 3D physical objects provide essential information to the users through their shape, weight, texture and colors, while the 2D digital layer can be used to display anything above and between the objects. Finally, TUIs facilitate bi-manual interactions: because of the tactile feedback, users naturally know in which orientation and configuration the objects lie in their hands. In comparison, touch interfaces require users to constantly check if they have selected a virtual item or if they are dragging it as intended Those advantages allow users to perform tasks more quickly and more accurately compared to touch interfaces (Tuddenham, Kirk, & Izadi, 2010).

12.2.2 TUIs in Education

Educational designers are generally enthusiastic about the potential of TUIs because manipulatives have been used for centuries to study how young children reason about the world (most notably by Piaget) and to progressively introduce them to abstract ideas. Friedrich Froebel (1782–1852), for instance, was a German teacher who created the concept of kindergarten. He designed a set of physical objects called “Froebel gifts” to help students learn about geometrical shapes and patterns. In one set, small cubes were used to introduce children to mathematical concepts such as addition, subtraction, multiplication and division. By explicitly integrating complex concepts into manipulatives, Froebel was among the first educators to design various sets of educational toys.

Later, Maria Montessori (1870–1952), an Italian educator, cleverly designed a different set of manipulatives to teach mathematical concepts in early childhood. For instance, she used golden beads to help children grasp the idea of large quantities and help them transition toward abstract numbers by associating stacks of beads with numbers (Fig. 12.2). Montessori programs are still alive, and it has been shown that children who were randomly selected to attend a Montessori program score higher on standardized math tests than children who had not been selected and attended a traditional program (Lillard & Else-Quest, 2006). Manipulatives have also been used to support learning of ratios, geometry, physics, and many other complex ideas in science. TUIs build on those successful applications, but they do not have to be limited to simple concepts such as addition or multiplication. Since the digital layer can represent anything, it is possible to design rich and complex learning scenarios that incorporate simulations, multiple external representations, dynamic scaffolding, just-in-time resources, and other mechanisms known to support learning. TUIs also support exploratory and expressive learning, they make learning activities more concrete, playful and engaging, they are well-suited to spatial domains, and have features that make them ideal for collaborative learning. Additional benefits of TUIs are summarized in Fig. 12.3 (reproduced from Marshall, 2007).

Considering the affordances of TUIs for learning, it is relatively surprising that there is not a wealth of educational environments leveraging this new technology. Many TUIs are created for artistic expression (e.g., the Reactable on the left side of Fig. 12.1) or for merely replacing elements of a traditional Graphical User Interface such as sliders, buttons or toggle switches (Schmidt et al., 2014). But there have been some attempts to design educational TUIs. For example, the Youtopia system (Fig. 12.4, left) allows young children to analyze the relationship between the economic development of communities and their available resources (renewable and non-renewable). Learners use physical tokens to "stamp" the landscape to modify it by building a facility, use resources or check their progress. A study found that assigning physical stamps to users supported more equitable verbal and physical participation compared to a control group where any player could use any stamp (Fan, Antle, Neustaedter, & Wise, 2014).

Another example is the TapaCarp system designed by Cuendet, Bumbacher, and Dillenbourg (2012; Fig. 12.4, right side). Apprentices in carpentry use physical

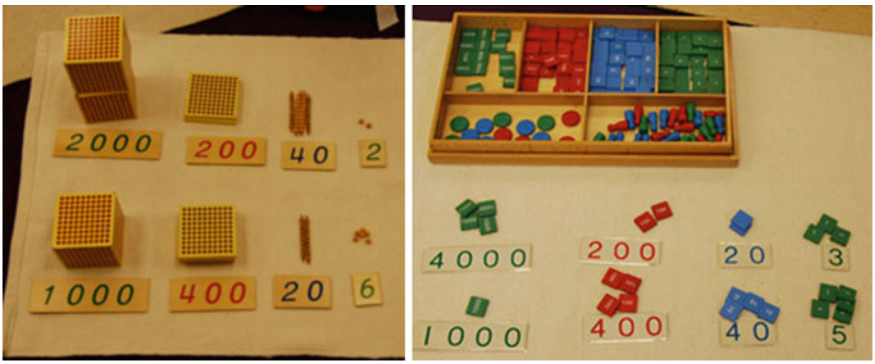

Fig. 12.2 On the *left*, golden beads used in Montessori schools. On the *right*, tiles used to facilitate the transition toward numbers

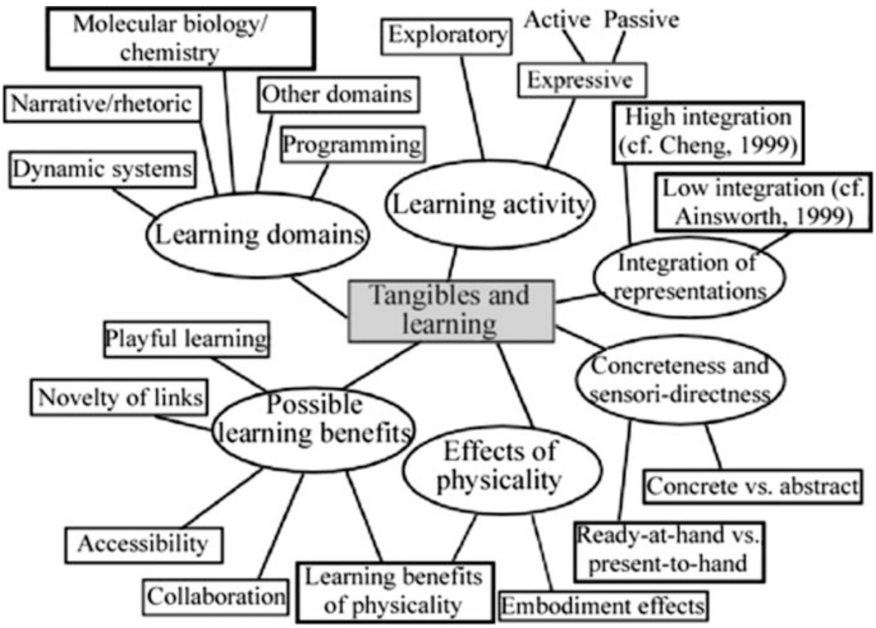

Fig. 12.3 An analytical framework that describe the potential benefits of tangible user interfaces (TUIs) in educational settings (Marshall, 2007)

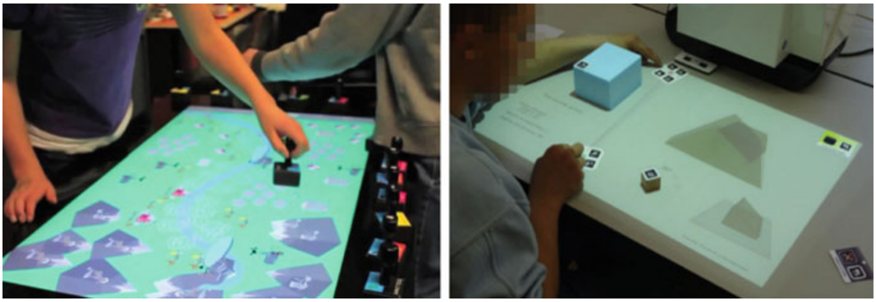

Fig. 12.4 Two examples of TUI in education. On the *left*, the TapaCarp environment allows apprentices in carpentry to train their spatial skills. On the *right*, the Youtopia system helps 5th graders to learn about sustainability in small groups

objects to understand orthographic projections displayed next to them. In one study, the authors found that tangibles helped students perform better compared to a virtual representation (it should be mentioned, however, that it did not significantly increase their learning gains). There are other examples of the benefits, and sometimes disadvantages, of TUIs for learning (e.g., Schneider, Jermann, Zufferey, & Dillenbourg, 2011). However, I will not describe them exhaustively here. Suffice to say that in some situations, tangible interfaces have affordances for learning that other interfaces do not have.

But what are the best ways to exploit the learning experiences that students have with TUIs? Below I introduce a framework that could answer this question, and provide designers with preliminary guidelines for integrating those new experiences with classroom instruction.

12.3 The "Preparing for Future Learning" (PFL) Framework

Even though the past decades have witnessed important technological innovations like NUIs, classrooms and online learning platforms still operate under the same principles that have existed for centuries. They favor a "tell-and-practice" (T&P) paradigm, where students are first exposed to a new idea, usually by a teacher giving lectures, and then given an opportunity to apply this new knowledge by solving exercises. Learning scientists (e.g., Bransford & Schwartz, 1999), however, have been criticizing this paradigm, showing that students gain a superficial mastery of the concepts taught. Instead, they argue that there is a "time for telling" (Schwartz & Bransford, 1998): "when telling occurs without readiness, the primary recourse for students is to treat the new information as ends to be memorized rather than as tools to help them perceive and think". Our first instinct is to solve this issue is by doing *more* telling. Schwartz and Bransford argue that under these conditions, students often think that they perfectly understand a concept, when in fact, they are missing the point.

Making sure that students are ready to learn from standard instruction is at the core of some constructivist frameworks. One of them, in particular, is the Preparing for Future Learning framework (PFL; Bransford & Schwartz, 1999). The PFL framework recognizes that more often than not, students come to the lecture hall without the prior knowledge necessary to understand the lesson. This theory suggests that instead, we should design learning activities where students can build some prior knowledge, develop curiosity for the domain taught and think critically *before* they are being told what the concept, formula or solution is. The PFL framework was originally developed to target one specific kind of prior knowledge: perceptual differentiation. The main methodology used to achieve this goal are *contrasting cases*. Contrasting cases are carefully designed representations of a concept, where some representations vary in terms of their *surface features* (superficial details that are unimportant) and their *deep features* (variables that are central to the concept taught). Students' goal is to analyze those cases to separate surface features and deep features. This way, when they are listening to a lecture or reading a textbook, they have a more refined understanding of which information to focus on (the deep features of a concept) and what to ignore (the surface features). This relates to the concept of authenticity discussed in Jacobson's chapter.

In various studies, researchers have found the PFL framework to yield positive results on students' learning. Schwartz, Chase, Oppezzo, and Chin (2011), for instance, taught adolescents about density using a set of contrasting cases (CCs) featuring buses of various sizes filled with clowns. The surface features were the types of clowns and buses. The deep features were the number of clowns and the size of the buses. Two experimental groups did the same activity, but in different orders. The T&P ("tell and practice") group was told the formula for density and then asked to practice this formula on the CCs. The constructivist group invented a formula for density using the CCs first, and were formally taught about density afterward. The authors found that even though both groups did equally well on standard word problems, the second group transferred the idea of density to semantically unrelated topics much more *frequently*. In a different study, Schwartz and Martin (2004) showed similar results where students in statistics had to create a reliability index for baseball pitching machines—in other words, they had to invent the formula for the concept of standard deviation from a set of CCs. They found that students in the PFL condition did better on a test that included additional learning resources compared to students who followed a T&P instruction.

In the next section, I explore how TUIs could be used as a preparation for future learning. While CCs focus on having students perceive details that they might otherwise miss, I suggest that TUIs have particular affordances that could also be used in a PFL fashion.

12.3.1 Tangible User Interfaces as a Preparation for Future Learning

This section describes learning environments that I have designed and/or evaluated in collaboration with others using cutting-edge technology for building mixed-reality interfaces (Fig. 12.5). This preliminary design cycle has explored domains as varied as neuroscience, math and probability, neuro-acoustics and logistics. In those examples, students learn about a complex system or a scientific phenomenon in a constructionist fashion by re-*constructing, de-constructing* or *re-assembling* its physical elements. The augmented reality layer displays digital information based on students' actions. For instance, it can project a simulation, a connection between two pieces, additional information or display hints. This kind of learning environment allows the system to dynamically adapt to users' actions and provide (to some extent) personalized learning experiences. This type of "just in time" feedback is especially useful for scaffolding students' learning. Figure 12.5 describes four TUIs designed for educational purposes.

On the top left of Fig. 12.5, the Brain Explorer system (Schneider et al., 2013) allows students to learn about concepts in neuroscience by interacting with a small-scale brain. They first take apart the physical brain regions, and the augmented reality layer displays visual pathways between the tangibles. Students can

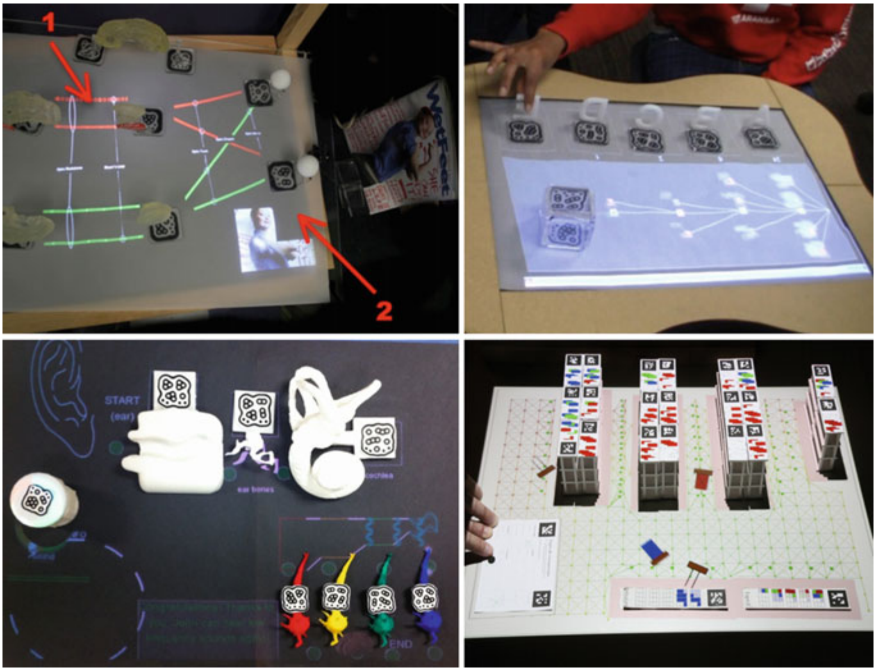

Fig. 12.5 Four examples of tangible interfaces in education: Brain Explorer (*top left*), Combinatorix (*top right*), Ear Explorer (*bottom left*) and the Tinker Table (*bottom right*)

then disrupt those pathways using an infra-red pen (arrow #1 on the picture), and the system displays the impact of those lesions on the visual field of this brain (arrow #2 on the picture). In this example, Mayer's loop is disrupted on the left side of the brain, which means that this subject loses the top right quadrant of his visual field. By repetitively iterating through different scenarios, students can start to build a basic understanding of how the brain separates visual information into four quadrants.

On the top right corner of Fig. 12.5, the Combinatorix system allows students to explore basics concepts in probability. By recombining the letters A, B, C, D and E, they build an intuitive understanding of how many combinations can be formed with those letters through the various visualizations that are displayed above them (e.g., a probability tree). The system then offers additional challenges, where various constraints are added. For instance, how many letters can be formed when E has to be the second letter in the sequence? Or how many letters can be formed when A has to be before B? By progressing through the various challenges and by analyzing the visualization displayed above the tangibles, students start to build an intuition about how the different formulas in combinatorics are structured.

On the bottom right corner of Fig. 12.5, The Ear Explorer interface allows students to rebuild the human hearing system from scratch. The goal is to recreate the pathway between the outer ear and the auditory cortex by connecting 3D-printed replicas of the organs of the hearing system. Students can then generate sound waves at different frequencies to test their construction and see which waves reach the brain. An important feature of the interface is the ability of students to make mistakes and build dysfunctional structures. They can then correct those errors by using the information box (i.e., the circle on the bottom left corner) where they place tangible items to access hints and can learn additional information about each organ.

Finally, on the bottom right corner of Fig. 12.5, the Tinker Table is a tangible interface for apprentices in logistics. Students learn about good design principles for organizing a warehouse by building a small-scale model, that they then analyze using more abstract representations such as graphs. This allows the teacher to provide concrete examples of interesting pedagogical situations, and to progressively move toward more formalized representations of warehouses' efficiency (e.g., equations).

This first wave of systems provided enthusiastic feedback from user and promising directions to follow. We learned one main lesson from building and testing those systems: using them as a stand-alone learning activity—where would students to learn everything about a phenomenon—is an extremely challenging task. We realized that using those systems for mastery learning was potentially misguided, and prevented us from using TUIs to their full potential. Instead, we observed that students were more likely to be intellectually and emotionally engaged about the underlying mechanisms of a phenomenon when interacting with a TUI. They became more curious, started to ask critical questions and engaged their peers into conceptual discussions. Those behaviors are important in their own rights, because they can also prepare students for future learning.

The main design guideline for those activities was to target the situation (mentioned by Bransford and Schwartz above) where over-telling students pushes them to "think that they know" because they have memorized information from a lecture when, in fact, they have large gaps in their knowledge. The learning activities on the TUI have the main function of helping students explore the domain taught and realize that there are subtle points that are more difficult to understand than expected. One side-effect of this intervention is to raise their curiosity: we also expect them to have more questions about the topic taught after having interacted with the TUI.

12.3.2 Empirical Findings

A series of controlled experiments combined the PFL framework with some of the TUIs shown in Fig. 12.5. The experimental design was a replication from Schwartz et al. (2011). College-level students interacted with a TUI either *before* or *after* following a standard kind of instruction (i.e., reading a textbook chapter or watching a video lecture).

In a first study (Schneider et al., 2013), we found that individuals who used Brain Explorer before reading an excerpt of a textbook outperformed students who used the TUI after reading the text on a learning test (Fig. 12.6, top left). Those results suggest that TUIs can be used to prepare students for future learning, and that using this kind of interface in a T&P kind of instruction is less effective. Additionally, we found differences in the quality of students' elaborations when thinking aloud. Students in the PFL group made more high-level comments (such as defining a rule based on a set of observations), which suggests that they tried to formulate their mini-theory of how the brain processed visual information. In the T&P condition, students made more simple observations (such as describing the effect of one lesion on the visual field of the brain) and repeating information from

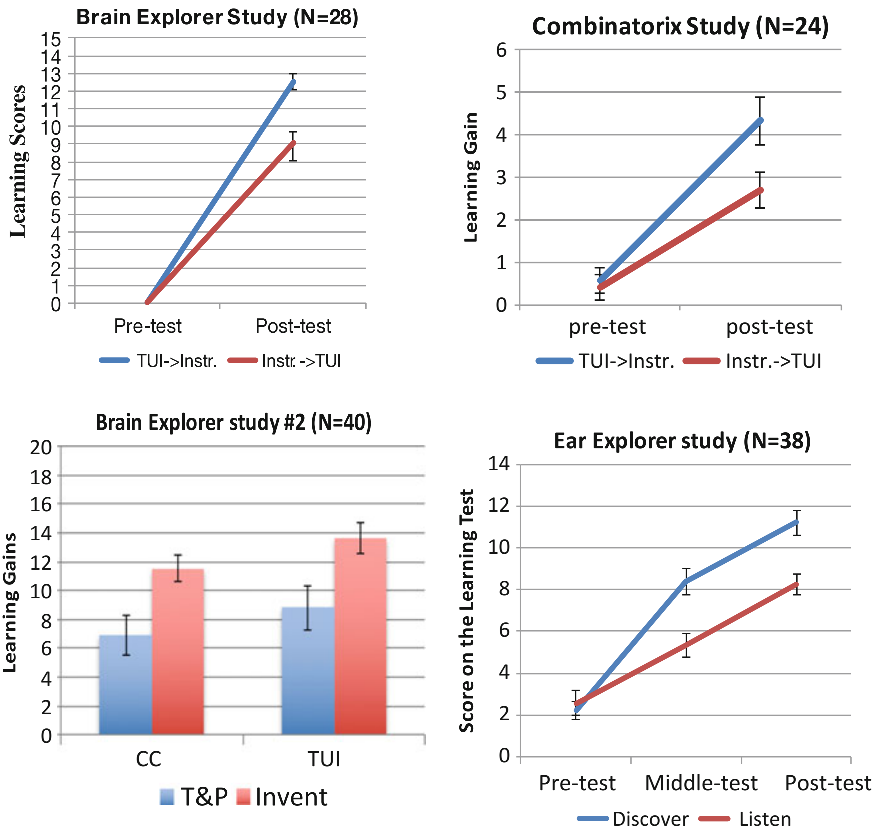

Fig. 12.6 Results of the 4 empirical studies where the PFL framework was applied to TUIs. The top figures compared the "tell and practice" paradigm (*red line*, also labelled as "Instruction → TUI") with the PFL sequence ("TUI → Instruction"). The *bottom left* graph replicates those results and compares TUIs with a set of Contrasting Cases (CC). The *bottom right* graph compares two PFL sequences and asks students to freely rebuild a complex system (discover) or follow step by step instructions (listen)

the text. Overall, we found that the quality of students' elaborations was a significant mediator for their learning gains. It suggests that the PFL sequence increased learning gains by having students construct their own mental model of the inner workings of the human brain—which they could then use to make sense of the text. Based on Bransford and Schwartz (1999)'s framework, we hypothesize that students in the T&P did not feel the same need to construct their own mini-theory: they likely believed that they knew how the brain worked, because they had the chance to memorize this information from the text. In other words, the text might have made them overconfident in their ability to understand the inner workings of the human brain.

In a second study (Schneider & Blikstein, 2015a, b, c), we replicated those results in a different domain (probability) using a pre-recorded video lecture where dyads of students interacted with the Combinatorix system (Fig. 12.5, top right). Again, students in the PFL condition outperformed students in the "tell and practice" group (Fig. 12.6, top right) on the learning test. We found that students in the PFL group explored the interface to a greater extent (e.g., they did more actions and accessed the visualizations more often) and spent more time discussing the concepts taught. On the other hand, students in the "tell & practice" group spent more time trying to remember information, such as formulas from the video lecture. This suggests that the T&P sequence pushed students to memorize, recall and apply information—at the cost of having in-depth conceptual discussions.

In the third study (Schneider & Blikstein, 2015a, b, c), we used a 2×2 experimental design to replicate those findings and compared the TUI (an updated version of Brain Explorer) with a set of Contrasting Cases (CC). CC are state of the art discovery learning activities, which is what was used in the PFL studies mentioned above. Additionally, we included two questionnaires between the activities. One questionnaire captured students' curiosity by asking them to write all the questions that they would like to see answered about the human visual system after the first activity. A second questionnaire measured the quality of their mental model by asking them to draw a diagram that summarized everything that they had learned so far. Again, we found that the students in the PFL condition outperformed students in the "tell and practice" group on a pre/post questionnaire measuring their learning gains. We also found that students who first interacted with the TUI built more complex mental models (as shown by the drawings they made between the two activities; see examples on Fig. 12.7) which was significantly correlated with their learning gains. They also became more curious (as expressed by the number of questions they asked themselves half-way through the study), which was significantly correlated with the quality of their mental model. This shows how the PFL sequence increased students' curiosity, which had a positive impact on the quality of their mental models. Better mental models, in turn, were associated with higher learning gains.

We also observed that learning gains were higher compared to a state of the art discovery-learning activity (Contrasting Cases). This does not mean that TUIs are better than CC for preparing students for future learning: it only means that for this specific domain, this specific TUI and CC, the interactive system yielded higher

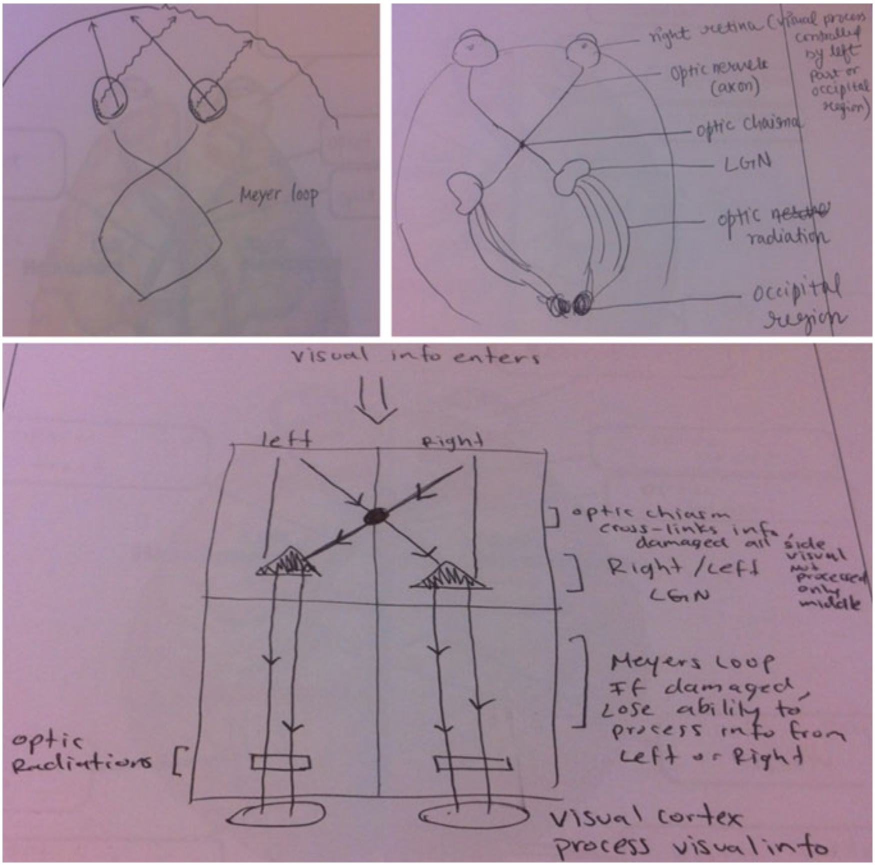

Fig. 12.7 Three categories of models drawn by the participants of study 3. The model on the *top left* has no or little useful information; the one on the *top right* has some useful information, mostly about the terminology; and the one on the *bottom* contains clear signs of conceptual understanding. Students in the PFL condition drew models that were more similar to the last two, while students in the T&P condition were more likely to draw models similar to the first two

learning gains for those students. This might be caused by a variety of factors: a higher engagement due to the novelty of the interface, the fact that complex systems might be a particularly good fit for TUIs, or because it is easier to collaborate around physical objects than a sheet of paper. Exploring this difference should be the focus of additional studies.

Finally, a last experiment (Schneider et al., 2015) refined the experimental design and clarified this difference. More specifically, we wondered if this effect was merely caused by the fact that students in the PFL sequence started the activity by physically rebuilding a system, which might have increased their engagement and carried over to the second activity. Similarly, it is possible that completing the standard instruction in the T&P sequence bored the participants and contaminated the second activity (i.e., when they interacted with the TUI). In summary, are the increased learning gains merely caused by a motivational effect? To answer this question, we used the Ear Explorer system (Fig. 12.5, bottom right) and asked dyads of students to rebuild the human hearing system from scratch. In one condition, they did so freely. In a different condition, a video of a teacher was displayed on the bottom right corner of the table, explaining the steps to follow to rebuild the system. Both groups then read an excerpt from a textbook which described how the human hearing system works. We found that students in the first group scored higher on a learning test, as shown on the fourth graph of Fig. 12.6 (bottom right). They also accessed the information box more often, which was significantly correlated with learning gains. It suggests that, when given the chance, students who could freely discover a domain were more likely to take advantage of additional resources. Finally, those results demonstrate that combining the PFL framework with TUIs is not about a quick boost in engagement that carries over the standard instruction: it is about having students actively build mental models of a concept, so that they can then use this prior knowledge to make sense of a lecture or textbook chapter.

In summary, those four studies provide evidence that using TUIs in a PFL fashion can significantly increase learning gains compared to a traditional T&P approach. More specifically, there are evidences that students in the PFL group were more likely to take advantage of the TUI, became more curious, made higher-level reflections, had more conceptual conversations and were able to build more complex mental models. In comparison, students in the T&P were more likely to spend their time recalling and applying information from a standard instruction (e.g., when watching a video lecture or reading a textbook chapter) and might have been overconfident in their ability to understand the concepts taught.

12.4 Preliminary Design Principles

Even though more research is needed to explore the effect described above, I suggest here a few preliminary design guidelines for creating technology-enhanced PFL activities. Those guidelines are based on my experience designing and evaluating those systems, and thus are not always supported by empirical findings.

1) **Target prior knowledge**: As mentioned above, the best use of Tangible Interfaces might not be to directly teach concepts to students, but to prepare them for future learning. The activity should be designed to help students build some prior knowledge, raise their curiosity, push them to ask critical questions and highlight potential misconceptions so that they can ground a teacher's explanations into a concrete, accessible experience—and not just refer to an abstract, formalized representation of the concept taught (i.e., equations or rules).

2) **When dealing with complex systems**: The studies above suggest that having students either physically deconstruct, reconstruct or recombine elements of a complex system is a potentially useful way to prepare them for future learning. It allows them to build a mini-theory of a concept as they are physically interacting with its different parts. Gardner's chapter provides some examples of this.
3) **Design coherent mappings to physical objects**: When designing a tangible system, a crucial decision is to choose what the physical objects will represent. Ideally, the tangibles should (1) make intuitive sense to the learners (for instance, it is clear what a brain represents; but it is less clear which idea a cube is supposed to embody), (2) activate their prior knowledge (e.g., we found that the shelves of the Tinker Table helped apprentices in logistics activate knowledge from their everyday workplace), (3) be central to the activity to support students' learning (e.g., by helping them explore a domain by quickly trying out combinations), and (4) propose synergies between the physical and digital layer (e.g., each representation should help the learners make sense of the other representation: a physical configuration should help students understand a simulation or a graph projected on the augmented reality layer). For more on this topic, the interested reader should feel free to consult Mina Johnson's chapter in this book.
4) **Foster curiosity and engagement**: Virtually all learning theories recognize that engagement is a necessary pre-requisite for learning. When designed well, tangible interfaces provide students with engaging ways to think about hard concepts in STEM, because they can represent and embody those ideas in a playful way (Marshall, 2007). This should be a central aspect to be kept in mind when designing an educational TUI.
5) **Making learning social**: Another advantage of TUIs is that they support collaborative learning in small groups, by making it easy to own and share physical objects. Social learning has been recognized as one of the most powerful ways to foster constructivist learning in the learning sciences and can be supported in tangible environments, as discussed in Kraemer's chapter Interactive tabletops, because of their size and shape, are natural environment for multiple users. It's a shared workspace where students are fully aware of each other's actions, which helps them externalize and share their thinking process. In a similar way, it serves as a "group working memory" where the set of objects represents the current state of the problem. Finally, collaboration can be facilitated by assigning roles (Schneider & Blikstein, 2015a, b, c) or tangibles (e.g., Fan, Antle, Neustaedter, & Wise, 2014) to students, which promotes engagement and participation from each member of the group. For a more exhaustive description of the benefits of interactive tabletops for collaborative learning, the interested reader can consult the review by Dillenbourg and Evans (2011).

12.5 Discussion and Conclusion

In this chapter, I have suggested that mixed-reality interfaces allow us to design new immersive learning experiences for teaching complex concepts in STEM. I have also described a framework in the learning sciences, called Preparing for Future Learning (PFL), which suggests ways to leverage those new learning experiences to enhance standard instruction. More specifically, empirical results show that having students reconstruct, deconstruct or reassemble a complex system on a TUI can have a positive impact on their learning, when this activity was used *before* a standard instruction (compared to a traditional T&P sequence).

Study 1 showed that neuroscience is a domain that could be particularly well-suited to a tangible implementation. When students used BrainExplorer in a PFL fashion, they were more likely to elaborate their own theory of the inner workings of the brain. In study 2, students who followed a T&P sequence tended to adopt a mechanistic behavior typical of classroom environments: they spent most of their time trying to memorize, recall and apply information from the lecture. They were also less likely to take advantage of the scaffoldings offered by the TUI. In study 3, there was evidence that students became more curious and built more complex mental models in the PFL sequence, and that the quality of their model was predictive of their learning gains. This really emphasizes the importance of helping students build prior knowledge that could be leveraged to understand standard instruction. The study also suggests that TUIs can be as good—or sometimes better—than state of the art PFL activities (i.e., Contrasting Cases). Finally, a fourth study clarified this effect. It showed that students did not learn merely because they could be physically active, or because of a novelty effect of the TUI: it showed that students who can actively build knowledge (via trial and errors, building hypotheses, testing them, and by freely exploring a domain) tended to learn more compared to the exact same activity where they are being told how things work. Additional studies should further refine this effect to design specific design guidelines for creating learning experiences that could be used in a PFL fashion.

In summary, the PFL sequence seemed to be helpful to students because it helped them become more curious. Their curiosity, in turn, supported constructivist learning. It became easier for them to create complex mental models that they could use to make sense of a standard instruction. The T&P sequence, on the other hand, seemed to promote a more mechanistic behavior: students tended to memorize and recall information, and they spent less time having conceptual reflections.

Those findings can be somewhat counter-intuitive because students and teacher tend to believe that the T&P sequence is usually more efficient. During informal interviews of study 1, students in the PFL group strongly believed that being instructed first would have helped them do a better job. Being immersed in an environment where they had to make mistakes and figure things out felt uncomfortable to them compared to the familiar T&P sequence. But the data shows that their intuition was wrong: they actually learned more by following a PFL progression. Additionally, when discussing with teachers during the Tinker Table project, they expressed reluctance to let students follow a PFL approach. For them, they had to teach students what they needed to know first. They did not feel comfortable letting students explore ideas on their own without being told what to do. Those observations reflect some deeply ingrained cultural beliefs about what counts as effective instruction.

Finally, there are a few obvious limitations that need to be mentioned. First, the activities described in this chapter were used to introduce students to concepts that were new to them. It is possible that the results would be different for students who already hold misconceptions about the concepts taught. Second, we found TUIs to be well-suited to spatial domains. It would likely be much more challenging to teach purely abstract concepts using tangibles. Third, the interventions were relatively short (20–30 min. for each activity). It is unclear if the findings above would hold for longer lessons. Finally, each study was conducted as a controlled experiment, which does not take the complexity of a classroom into account. Future work should study how this effect can be transferred to formal and informal learning environments.

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Chapter 13
Conclusion—Strategic Planning for R&D on Immersive Learning

Christopher J. Dede and John Richards

Abstract This chapter articulates a Grand Challenge of applied, collective research. In our judgment, we must establish educational research laboratories with access to the next generations of tools and complementary research agendas to rapidly accumulate knowledge. Immersive technologies cannot be examined in the hope of changing one parameter and observing the effects. Rather, immersion, particularly VR and MUVEs, by their very nature alter perspective, context, and even the participants' sense of self, while immersion in the form of MR and AR alters our sense of participation in the external environment. Design strategies for this scholarly work include applied, collective research; studies on what works when for whom, it what context; and research balanced between design and evaluation. Our illustrative research agenda includes thematic areas: authenticity, representation of the self, social immersion, and technological support and infrastructure. We also suggest developing implementation testbeds that provide authentic contexts to judge the educational value of immersive learning experiences.

Keywords Strategic planning · Immersive learning
Research and development

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13.1 Next Steps for the Research Community

As the book chapters illustrate, researchers have found that immersive media have great potential to promote enriched curricular content, active forms of learning, performance assessments with high validity, and the application of academic learning to real world situations. However, much work remains to be done before these educational technologies will be truly practical, affordable, and scalable. That goal will require much greater, more targeted, and more sustained support for research and development than the piecemeal funding that exists today, offered mainly through a handful of intermittent federal and corporate programs. At present, the most important priorities for scholars are (1) to design and study high-quality educational environments that promote situated learning and transfer in areas where immersion can make a big difference in student outcomes, and (2) to help education stakeholders grasp the value of these learning media, understand metrics for judging quality, and increase investments in this approach.

13.2 Important Dimensions for Research Design

Applied, collective research: At present, an important priority is for studies that produce "usable knowledge" about technology-enhanced instruction, motivated primarily not by intellectual curiosity, but instead out of a desire to address persistent problems in practice and policy (Dede, 2011). This is not to disparage basic research or theoretical work, which is required particularly for types of immersive learning that have no precedent in prior educational research (e.g., mixed realities, transformed social interaction), as discussed later. However, in immersive learning at present, greater investments in applied research are warranted. The process of creating and sharing such usable knowledge is best accomplished not by scholars working in isolation, but instead by a community of researchers, practitioners, and policymakers. While individually developed "outlier" ideas can be valuable and should be some part of the research agenda. However, if the goal is to develop and invest in immersive media that promote greater learning, then what is required is a multi-dimensional perspective, touching on the whole range of academic, inter-personal, and intra-personal capacities that have been shown to matter to young people's long-term success. That sort of "grand challenge" necessitates a group effort, combining various research methods and integrating knowledge from several fields, from cognitive psychology to teacher capacity building to curriculum studies to educational technology.

Fully understanding a complex educational intervention involving immersive media that is effective across a wide range of contexts may require multiple studies along its various dimensions, each scholarly endeavor led by a group that specializes in the methods best suited to answering research questions along that dimension. Using such a distributed research strategy among collaborating investigators, funders could create portfolios in which various studies cover different portions of this sophisticated scholarly territory, with complementary research outcomes enabling full coverage and collective theory-building. Further, once the efficacy of an intervention is determined via exploratory research, a single large effectiveness study with a complex treatment is of greater value for research than multiple small studies of individual simple interventions, none of which has the statistical power to determine the nuanced interaction effects described next.

Research on what works for whom, in what context: Numerous studies document that no single pedagogy is optimal for all subject matter and every student (Dede, 2008). Education developers too often assume that innovations cannot be brought to scale unless they can be replicated precisely and implemented with fidelity. However, experience has shown that the successful implementation, use, and spread of learning technologies often depends on the adaptations to a particular setting that they undergo at the local level. Therefore, the best way to invest in new technologies for immersive learning is to acknowledge that context matters; these media must be designed for customization to serve a range of educational settings, their teachers and students, their curriculum, and their culture. In brief, such tools should be designed with local adaptations in mind, and professional development should include building educators' capacity to make these adjustments. Therefore, statistical power in research studies about efficacy is important because, rather than assuming that an educational technology is "effective for all learners" in some universal manner, research and development should focus on what works for whom, in what contexts (Means, 2006).

Research balanced between design and evaluation: A research agenda should respond both to stakeholders' needs for evaluative studies and the designers' needs for research that informs design and theory. Too many studies now privilege the former over the latter. A "blended" empirical research model designed not only to answer questions about whether a program design works well, but also to provide evidence to explain why it works well seems a reasonable and effective alternative to the evaluation-centric approach now prevalent. Such a research strategy also mitigates researcher-practitioner tensions: On the one hand, the need for evaluation-based marketing to potential adopters of immersive media is a 'necessary evil' for many scholars. On the other hand, the more theoretical work of explaining why and to what extent design interventions work is at best the 'icing on the cake' to developers and vendors of educational games and simulations, who know that ultimate sustainability depends on creating an evidence-based commercial product.

Thus, a research agenda for immersive learning should focus on applied, collective research; adaptation of learning environments based on what works for whom, in what context; and a balance between design-based studies and evaluations of effectiveness.

13.3 Illustrative Research Questions Suggested by the Chapters in This Volume

Below are illustrative research questions suggested by the chapters in this volume. The intent is neither to display a complete list of possibilities nor to claim that these constitute the "best" research agenda, but instead to start a dialogue about what such an agenda might include and how it might be formulated.

Authenticity

- To what extent can immersive media replicate via simulation various types of authentic practices learners can master and transfer to the real world?
- For various types of objectives for an immersive learning experience, which types of authenticity are most important, and what design heuristics can be used to create these? (Jacobson's analysis of authenticity provides guidance for the level of detail required in different contexts.)

Representation of the Self

- For various types of objectives for an immersive learning experience, when is embodied learning important, and what design heuristics can be used to realize this? (Johnson-Glenberg's exploration of embodiment describes ways to bridge the distance between the immersive experience and learning educational content.)
- To what extent do having experiences that convey an alternative perspective embodied in a body not your own result in implicit changes in attitude and behavior? (Slater's research on racism and on access to mental resources illustrates this question.)
- Do pedagogical agents that resemble oneself result in more effective learning? (Kraemer discusses various design strategies for pedagogical agents and for transformed social interaction.)

Social Immersion

- How can VR technologies foster learning via optimizing social interactions between teacher and learner, or between learners in collaborative learning environments? (Gardner describes various design strategies to enhance learner collaboration and interaction.)
- For various types of objectives for an immersive learning experience, which types of social immersion are most important, and what design heuristics can be used to create these? (Klopfer proposes that massively multiplayer games will provide a level of engagement—in his terms, investment–that supports social learning and exploration.)

Technical Support and Infrastructure

- For various types of objectives for an immersive learning experience, what heuristics can determine which type of immersive medium (e.g., virtual reality,

MUVE, mixed reality) will be most effective? What heuristics can determine when transmedia design (blending these) adds substantial value for learning? (Dede discusses transmedia narratives as a means of enhancing learning.)
- What design heuristics can reduce issues of comfort and of registration in immersive learning experiences?
- What infrastructure is required for immersive technologies to be successfully brought to scale in the school environment? (Richards articulates both the technological requirements and the design requirements necessary for broad acceptance.)

Research

- What frameworks for terminology and taxonomy can best aid communication among scholars in immersive learning? (Liu and Huang propose frameworks that could address this need.)
- For various types of objectives for an immersive learning experience, which multi-model dimensions add most value in understanding effectiveness? (Schneider describes frameworks for interrelating these dimensions.)
- What design heuristics can maximize transfer by manipulating presence, authenticity, embodiment, saliency, and identity?
- Through which types of instructional design can immersive media help learners to develop affective capabilities, such as self-efficacy, growth mindset, tenacity, initiative, flexibility, and conscientiousness?
- Through which types of instructional design can immersive media be scalable via adaptation to local settings?
- For students who need direct instructional supports embedded in immersive learning experiences, what are effective models for accomplishing this without undercutting engagement and flow? (Shute discusses the use of stealth assessments to aid learning and teaching.)
- What capabilities do teachers need to use immersive media effectively in formal educational settings? What types of professional development and peer-based learning will most aid teachers?

This is an incomplete list of high-level research questions—it illustrates a method for generating a research agenda by aggregating and categorizing the research foci of various scholars studying immersive learning. This initial list was derived based on the assumptions articulated above: usable knowledge, collective research, adaptation to specific situations, and a balance of design and evaluation are all represented as cross-cutting themes.

13.4 Developing Implementation Testbeds

Integrating research into educational practice involves three steps (Carlile, 2004): *Transfer* from research to practice, *Translation* of research into practice, and *Transformation* of practice based on research. The initial stage, Transfer, is insufficient because it reflects the traditional one-size-fits-all scale-up model that has not led to sustainable improvements. Translation and Transformation involve major shifts in policies and practices as mutual adaptation between local contexts and research-based innovations. In this process, risk-taking is essential. For example, it's crucial to see experiments that are "informative failures" as a success in advancing knowledge.

Researchers typically struggle to find even small numbers of classrooms and schools, practitioners and policymakers, willing to engage in this type of risk-taking and experimentation. Therefore, educational testbeds are needed that provide authentic contexts for Transfer, Translation, and Transformation based on immersive learning. This requires substantial numbers of classrooms and schools willing to move beyond the traditional instructional and assessment models of practitioners, the conventional ideological and political standards of policymakers, and the usual rigorous practices and evidence standards of researchers. Finding venues willing to undertake immersive learning at scale is a substantial barrier to implementing the research agenda described in this volume.

13.5 Concluding Thoughts

For immersive media, the prices are cycling down, and the experiences that are available now on high-end devices will be cost appropriate for schools in the next few years. Anticipating these developments, we have articulated a Grand Challenge of applied, collective research. In our judgment, we must establish educational research laboratories with access to the next generations of tools and complementary research agendas to rapidly accumulate knowledge.

The research agenda we have outlined presents intricate challenges, perhaps best summed up by Marshall McLuhan, "There is no *ceteris paribus* [other things being equal] in the world of media and technology. Every extension or acceleration effects new configurations in the over-all situation at once" (1964, p. 167). Immersive technologies cannot be examined in the hope of changing one parameter and observing the effects. Rather, immersion, particularly VR and MUVEs, by their very nature alter perspective, context, and even the participants' sense of self, while immersion in the form of MR and AR alters our sense of participation in the external environment. This book documents the most advanced work completed to date in order to understand the applications of immersive technologies to learning and education, but also demonstrates how early stage our current understandings are. We have only scratched the surface of understanding the educational implications of these technologies.

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Glossary of Terms Related to Immersive Learning

Forms of Immersion

Sensory Immersion The experience of having your senses mostly or totally surrounded by a three-dimensional "view" of a virtual world. For example a head-mounted display (HMD) or a planetarium dome shows you the virtual environment in (almost) any direction you look. A good pair of stereo headphones can immerse your hearing in an unreal soundscape.

Psychological Immersion The mental state of being completely absorbed or engaged with something. Because psychological immersion is a state of mind, it could be brought about by a variety of situations (such as reading a book or watching a movie).

Immersive Media Media that use sensory immersion to induce psychological immersion in the viewer or participant. These include Virtual Reality (VR), Augmented Reality (AR), all manner of Mixed Reality (MR), and to a lesser extent other large-format media such as movie theaters or planetariums.

Virtual Environment (VE) The digital world which the user occupies. For example, a person wearing an HMD will see the VE all around him or her, while a user in a MUVE or a single-user VR will see his/her avatar at a specific place in the VE. The term does not apply to any mixed or augmented reality; a virtual environment is digital and takes the user (figuratively) somewhere else.

Multi-user Virtual Environment (MUVE) A virtual world accessed by one or more people, usually many people. Each person is represented by a (usually) humanoid character that s/he controls (an avatar). Technically, MUVEs are not immersive media, because they are usually accessed through a standard computer or mobile interface. However, they achieve many of the same psychological effects.

Virtual Presence (Place Illusion) A particular form of psychological immersion, the feeling that you are at a location in the virtual world. For example, using an head-mounted display to see a virtual room in every direction you look, makes

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you feel like you are in that room. MUVEs achieve a similar form of presence, though the user's emotional investment in their avatar.

Actional Immersion Empowering the participant in an experience to initiate actions that have novel, intriguing consequences. For example, when a baby is learning to walk, the degree of concentration this activity creates in the child is extraordinary. Discovering new capabilities to shape one's environment is highly motivating and sharply focuses attention.

Symbolic/Narrative Immersion Triggering powerful semantic associations via the content of an experience. As an illustration, reading a horror novel at midnight in a strange house builds a mounting sense of terror, even though one's physical context is unchanging and rationally safe. Narrative is an important motivational and intellectual component of all forms of learning. Invoking intellectual, emotional, and normative archetypes deepens the experience by imposing a complex overlay of associative mental models.

Interfaces

Augmented Reality A form of mixed reality: Real world situations enhanced for learning by overlays with virtual information and experiences, presented on mobile devices (e.g., looking at a statue and seeing history about the person superimposed through the camera view of a tablet).

Haptics Using touch and pressure in a sensory experience (e.g., learning surgery on a virtual patient with sensory feedback on the incisions you make).

Tangible Interfaces A form of mixed reality: Interactive experiences manipulating objects that have both real and virtual components (e.g., manipulating physical blocks that, as you move them around, provide virtual overlays about geometry).

Cognitive Science

Situated Learning "Situated" learning takes place in the same or a similar context to that in which it is later applied, and the setting itself fosters tacit skills through experience and modeling. For example, in a medical internship, both the configuration and the coordinated team activities in a hospital surgical operating room provide embedded knowledge.

Transfer Transfer is the application of knowledge learned in one situation to another situation, demonstrated if instruction on a learning task leads to improved performance on a transfer task, typically a skilled performance in a real-world setting. For example, statistical reasoning learned in a classroom can potentially aid with purchasing insurance, or with gambling.

Plan/Act/Reflect (PAR) Students first prepare for an experience by doing something they want to master, then they attempt that performance, and finally they assess what went well, what did not, why, and what they need to learn in order to execute a more successful repetition of the cycle.

Embodied Cognition An instructional strategy that posits retrieving a concept from memory and reasoning about it is enhanced by creating a mental perceptual simulation of it.