Experiential mixed reality learning environments for design education

Xiangyu Wang
Key Centre of Design Computing and Cognition
Faculty of Architecture, Design & Planning, University of Sydney, Australia
Email: x.wang@arch.usyd.edu.au

Abstract: Nowadays, it is becoming more and more popular for teaching and learning to be supported in technology-supported settings and these digital technologies lead to new instructional methods. Mixed Reality (MR) technology can create an innovative and seamless learning space by merging computer-generated elements of virtuality into a real space. It is envisaged that combination of real and virtual media opens new perspectives for teaching and learning. There are ranges of visualization modes embraced by the broad concept of MR, among which two major modes are Augmented Reality and Augmented Virtuality. Different cognitive and social-learning processes are involved with learning supported by these technology modes. This paper develops a framework/taxonomy for designing and implementing Mixed Reality learning environments (MRLEs) to improve the pedagogical effectiveness of learning processes in design education. This framework involves three major dimensions: Mixed Reality technology modes, learning styles and interaction modality. As a case study of this taxonomy, urban design education was chosen to illustrate the potentials of MR-supported learning spaces.

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INTRODUCTION

Current design education involves the critical need to integrate theoretical and practical learning sequences. There are proved benefits from interleaving theoretical and practical learning (Attwell and Brown 2000) and there is a growing need for innovative teaching and learning concepts and technologies which can support such integration. E-learning and virtual learning environments (VLEs) apparently are lack of integrating digital learning systems into real-life working practice.

In order to tackle this issue, the taxonomy for Mixed Reality (MR), as set forth by Milgram and Colquhoun (1999) encompasses the continuum of possible combinations of elements from both virtual and real environments, the continuum between fully real and fully virtual. Figure 1 illustrates this Reality-Virtuality (RV) continuum associated with noted education-related examples. Augmented Reality and Augmented Virtuality are the two major modes in MR, but more visualization modes of real and virtual mixing/merging can be further identified. Closer to the fully real end of the continuum is Augmented Reality (AR), where the image of a predominantly real scene is enhanced with digital content. Toward the other end of the spectrum is Augmented Virtuality (AV), the opposite of AR. Visualization modes in MR open perspectives for eliminating the original separation of the real and the virtual, therefore, Mixed Reality concept can extend the E-learning and VLEs to real world or even to the workplace. The concept can facilitate the bridging between practical experience from constructive activities and symbolically communicated experience from analytic activities. Design education must take this need for integration into consideration and devise appropriate learning modes in which MR acts as an excellent opportunity for creativity and effective communication. MR has been rarely explored worldwide and there is paucity in research of investigating MR in design education. The author defines an educational environment that incorporates these virtual technologies as Mixed Reality learning environments (MRLEs), due to the common concept of students learning within an interactive environment containing some artificial components. Students can test and construct their own knowledge by interacting with their MRLEs, and the learning environment has to be developed in such a way as to facilitate learning through interaction with the content. Using MRLEs involves high pedagogic potentials which are envisaged to significantly contribute to pedagogical effectiveness in learning processes.

Although recent years have seen major efforts being invested in E-learning and virtual learning environments (VLE) as tools of supporting and fostering learning, current studies in this field have revealed some general shortcomings and above all a lack of options for integrating digital learning systems in real-life work situations (Severing 2003). Learning in physical environment (e.g., classroom) and learning in virtual environments (e.g., eLearning) occupy the two extremes along the RV continuum in Figure 1 with different learning cultures. It is envisaged that visualization modes in MR can open doors for overcoming this opposition and removes the original separation between the real and virtual. This position paper develops a framework where the author evaluates exploratory, experiential, and collaborative Mixed Reality learning environments to improve the design pedagogical effectiveness. More specifically, the author conducted the determination of technology suitability that theoretically maps from alternative MRLEs to learning styles/education methods based on experiential and collaborative learning theories. The important thing is to map a variety of virtual tools (e.g. simulations) to different education/training methods (theory courses, laboratory teaching, learning in the workshop, online tutoring, self-paced learning, etc.).
1. TAXONOMY OF MIXED REALITY LEARNING ENVIRONMENTS

On the basis of the experiential, social constructivism (Burr 1995) and collaborative learning theories, specific MRLEs are further defined in a global (three-axis) continuum that also addresses the MRLEs modes, learning styles, and interaction modality (see Figure 2). The first dimension in this taxonomy is the MRLEs modes which forms the continuum between physical reality and digital virtuality in respect of different visualization modes. It is the form in which the MR learning space is presented. For instance, the virtual learning materials can be put into real teaching environment (Augmented Reality), or real learning materials can be inserted into the virtual teaching environment (Augmented Virtuality). The second dimension acknowledges the broad diversity of learning styles between constructive and analytical learning and derives from Kolb’s four-stage learning cycle (abstract conceptualization, active experimentation, concrete experience, or reflective observation) (Kolb 1984). MRLEs generate new perspectives for linking constructive learning (e.g., constructing real elements) and analytic learning (e.g., cognitive understanding of virtual components). The third dimension is modality for interactive learning in MRLEs: visual, auditory and kinesthetic.

1.1. Learning media and tools

The first dimension in this taxonomy is the continuum between physical reality and virtual reality in respect of different learning modes. These range from physical, real-world instructional tools and media to purely virtual tools and media (see Figure 2). An example of the former is learning with real tools in an actual working process. At the other end of the dimension we have learning with purely virtual environments, in virtual laboratories or with computer simulations (Fishwick 1995). Between these two extremes there are various mixed forms, such as learning with and on physical systems and processes of reduced complexity, but close to reality nevertheless. Learning in physical reality involves direct contact with physical objects. On the other hand, direct, sensomotoric experience with physical objects are a basic requirement for ‘grasping’ the material involved. Piaget (1973) drew attention to this phenomenon long time ago, when he described how cognitive development is generally rooted in the child’s manual, tactile interaction with the objects in its environment. In the same way as manipulated objects respond with a specific reaction (due to hardness, elasticity,
roughness, heat, cold, etc.), the manner in which individuals deal with them is rooted in action schemes, mental images or cognitive models. In addition, research has shown that the key to acquiring the necessary motor skills to control complex systems is hands-on and coached training (Cuqlock-Knopp et al. 1991). Design education such as architecture and urban design education must take this aspect into consideration and devise appropriate learning situations. Sensory interaction with real learning objects is helpful in learning complex interrelationships. Therefore, it is apparent that physical objects must be used in their place.

1.2. Learning styles
The second dimension derives from the fact that learning activities vary with a broad diversity of learning processes underneath. These can basically classified into two categories: constructive and analytical. Constructive activities are practical, whereas analytical activities consist of more rigorous steps such as observing, reasoning, interpreting, reflecting, etc. (Müller 2005). However, this does not mean that the analytical activities interfere with the reality, but only subject the reality to analysis. In contrary, constructive activities may interfere with the reality and create new objects or remove existing objects. From the technical perspective, Mixed Reality concept can bridge this gap between the real and virtual, and more focus on how the real and virtual can be combined together to fulfill different learning objectives, requirements, and even environments. Constructive activities are aimed at building real components, analytic activities at cognitive understanding of virtual components (Ferreira and Müller 2004). From the perspective of learning activities, this concept facilitates the bridging between direct and practical experience learned from constructive activities and symbolically communicated experience learned from analytic activities (Müller 2005). For instance, Mixed Reality can become a link for connecting physical mock-up experience (from constructive activities) and abstract modelling (from analytical activities) in the context of architecture education.

As indicated in the Figure 2, between the two extremes, there lie more specific learning styles which are identified from the four-stage mode by Kolb (1984). The major four learning styles are abstract, concrete, active and reflective learning. A learning process begins with a concrete experience, which is then followed by reflective observation. The reflection can then be assimilated into a theory by the process of abstract conceptualisation. Lastly, new or reformulated hypotheses are tested out in new situations. The model is an iterative learning cycle within which the learner tests and modifies new ideas and concepts as a result of reflection and conceptualisation. One of the critical issues in educational methods is that the teaching style offered does not always significantly addresses the learning style preferred by students. It is therefore useful to combine different teaching methods/techniques to cover different aspects of what needs to be learned. Under such circumstance, MRLEs are envisaged to be suitable as a supplemental teaching aid to other teaching methods instead of a sole technique on its own.

1.3. Multimodal learning types
Learning modality can be broken into three modes: visual, auditory, and kinesthetic. Most people have a preferred mode of learning. Some people can use more than one mode equally as well. We all have preferences for how we absorb information, analyse it and make decisions. Some people like to see what you mean and make decisions based on how things look. Some people like to hear your ideas and decide based on what they sound like. Some people like to experience what you are talking about and decide by how things feel to them. Visual learners usually need to see it to know it. Visual learners should use graphics to reinforce learning such as films, slides, illustrations, diagrams and doodles. Auditory learners usually prefer to get information by listening-needs to hear it to know it. Auditory learner should use of tapes for reading and for class and lecture notes, and learning by interviewing or by participating in discussions. Kinesthetic learners usually prefer to hands-on learning. They learn better when physical activity is involved. Kinesthetic learners should engage in experiential learning (making models, doing lab work, and role playing). They trace letters and words to learn spelling and remember facts. They use computer to reinforce learning through sense of touch. Understanding students’ personal learning style can improve their own learning process, and assist them in communicating with other people.

1.4. Discussion
Precise identification of a MRLE’s position in the global continuum is no simple matter and depends upon the learning environment’s specifications. An environment might even have specifications that span significant portions of a continuum. Figure 2 represents an attempt to globally classify three of the noted MRLEs examples, making certain assumptions about the specifications. For example, the tangible Augmented Reality interface for urban design education which is presented in the section 3 is assumed to be visual and kinesthetic, considering it is geared towards practicing urban design principles from concrete manual experience. In terms of the learning style addressed, the AR system is more suitable for constructive type of activities. Also shown in the global taxonomy, the case of virtual reality demonstration of certain challenging building methods apparently should be located towards the virtual extreme along the MRLE modes. As far as the interaction modality is concerned, it is predominantly visual because it is an animation-like demo which requires very few interactions from the students. The reason why it is located to the upper range of learning styles is that this type of learning more concerns with the abstract learning of building methods rather than actual implementing the method on sites. Based on the above justifications, this case should be located in the position shown in the Figure 2. For the case of e-learning with video images of instructors, apparently this mode belongs to Augmented Virtuality which inserts the real video image of instructors into the virtual e-learning environment. It is also limited to visual and audio because they are the major channels that can be enabled via network. Lecture-type instruction makes it positioned to the analytical extreme in terms of learning style. Methodologies to determine specifications for any environment constitute fertile ground for research experimentation that draws upon both physical and psychological human factors knowledge and integrates advanced MR technologies to improve the delivery of digital teaching and learning materials/contents.
2. CASE STUDY: AUGMENTED REALITY FOR URBAN DESIGN

Based on the preliminary work on the formulation of MRLEs global continuum, there should be a further mapping to address this issue by theoretically three-way mapping among alternative MRLEs modes (e.g., AR and AV), learning styles (e.g., theory courses, laboratory teaching, learning in the workshop, online tutoring, self-paced learning, etc.), and interaction modality (e.g., visual, audio, etc.) The cognitive strategies and cognitive load characteristics of each MRLE mode should be exploited and applied. For instance, the understanding and reinforcement of concepts/theories learned from lectures on urban design demand problem-based experiential learning approaches. Immersing students into an Augmented Reality tangible environment where manipulating the virtual buildings onto a real photo of site layout via playing around real markers as used in wood block method, provides rich opportunities for exploratory learning because students can ‘experience’ theory in a familiar form, and “observe and reflect on” the results of learning tasks and assignments (Wang 2007).

As an initial step towards this objective, this section presents the discussion of a case study based on the results and justification from the global taxonomy presented in the last section. Firstly, it is important to investigate the aspects of learning style that are especially significant for urban design education. Urban design can be regarded as knowledge-based behaviour where the goal is explicitly formulated. In order to reach the goal, different plans are developed and their effects mentally tested against the goal. Finally, a plan is selected. Serious complications that occasionally occur during urban design require a great deal of knowledge-based behaviour. Students have to analyze such complication together with the aim of the design procedure in order to develop strategies to counter the complication. Then students have to select the best strategy and consequently take the appropriate actions.

Traditional instructional methods are not sufficient to educate urban designers, which is normally associated with testing design principles and theories with wood blocks. Instructional methods would never be sufficient to educate urban designers, who need to practice with wood blocks and principles in simulated urban layout. These developments in "what is learned" have clear implications for the use of instructional methods. The learning activities and experience designed in MRLEs can help students to integrate the knowledge, skills and attitudes necessary to deal with real-life problems. An Augmented Reality tool as shown in Figure 3 is developed that can enable students to learn in a "what if" and "play and learn" environment (Wang 2007). Students can generate several design solutions and visualize them in an AR environment where virtual designs can be manipulated with tangible interface in a natural manner. Students can then make decision on the best solution based on design principles and theories learned in the lectures. The AR system can deliver the design idea across a group of students in one discussion room with a large projection screen, thus allowing more social interactions. The AR system that was developed consists of a PC, a large screen, a video camera as sensing device, and tracking markers. The AR system is based on ARToolkit, which can overlay virtual imagery onto the real world object. The virtual objects are pre-modeled by ArchiCAD and therefore designers can quickly develop new models according to the design requirements. The following sections are the three major justifications of the benefits of using Augmented Reality for urban design education:

2.1 From the perspective of social constructivism:
In a classroom setting, students work together better if they focus on a common workspace instead of being separated. When students work at a table, the space between them is regarded as communication space that is used for sharing communication cues such as gaze, gesture, and nonverbal behaviors. If the people are talking about objects on the table, then the task-space is a subset of the communication space (Billinghurst 2002). Students can see each other and the shared communication cues at the same time as the objects they are discussing. This results in conversational behavior that is more similar to natural face-to-face collaboration than to screen based collaboration (Kiyokawa et al. 2002). This AR system focused on supporting social learning practice based on social constructivism, combined with experiential and collaborative learning.

2.2 From the perspective of active implementation and concrete experience
Among many important learning models, learning starts when the learner experiences practical or cognitive dissonance. In urban design classroom settings, the learning process is usually simulated by problem-based learning situations. The student is presented with a specific construction of the world, for example using a textual description, or a problem that needs to be solved. Students may also collaborate in solving the problem, for example, by taking different roles and manipulating three-dimensional virtual objects simply by moving real tracking markers that the virtual models appeared attached to (Poupyrev et al. 2000). 3D AR environments offer a richer form of experiential learning not available previously.

The theory of experiential learning, which is an important reference point in this approach, propagates learning through experience and by experience. MRLEs, simulation-based learning environments, can present objects with natural affordances for supporting interaction. Thus, students are able to act directly upon virtual objects in the environment, and this can create a sense of presence — of “being there” — in the virtual learning environment. Consistent with Kolb’s experiential learning framework, AR allows students to acquire concrete learning experiences through active experimentation. As students together “play” with the AR simulation, they actually start to engage themselves into mutual problem-solving activities for the purpose of searching for a consensual solution.
2.3 From the perspective of first-person learning
MRLEs can technically afford a first-person form of immersive or semi-immersive experiential learning. Apparently, the traditional instructional method in urban design is based on third-person knowledge, where students learn without the opportunity to directly experience what they learn. Research in third-person learning revealed that student learning outcomes are usually shallow and retention rates are low. A first-person learning experience in MRLEs can enable exploratory learning which has the advantage of giving students control over their own learning experience. Because of the way in which the MRLEs are constructed, students’ actions always involve immediate feedback from the reality. This feedback provides a natural mechanism through which students can judge whether they have taken appropriate learning activities in MRLEs.

CONCLUSION AND FUTURE WORK

Mixed Reality (MR) technology can create an innovative and seamless learning space by merging computer-generated elements of virtuality into a real space. It is envisaged that combination of real and virtual media opens new perspectives for teaching and learning. This paper develops a taxonomy/framework for designing and implementing Mixed Reality learning spaces to improve the pedagogical effectiveness of the learning processes in design education. This framework is developed to support learning practice on the basis of two types of learning theories: experiential and collaborative learning. The paper also identifies three major factors that should be considered in designing MR learning space. As a testbed of this framework, urban design education was chosen to demonstrate the potentials of MR-supported learning spaces. Motivated by this, an MR tool was developed that can enable students to learn in a “what if” and “play and learn” environment. Students can generate several design solutions and visualize them in an MR environment where virtual designs can be manipulated with tangible interface in a natural manner.

Future work will develop MRLEs technological infrastructure and working examples that can be shared by different units of study across the faculty/institutions. The formulation of this taxonomy is crucial, forming testing assumptions for experimentation/evaluation in the next stage. The hypotheses will be formulated and developed in terms of cognitive processing demands, stimulus and response elements, and the employed cognitive strategies. The learning scenarios assessed in each MRLE mode will be devised to address various design projects and cases of applications. The author proposes to further address this issue by testing and validating the mapping of MRLEs to learning style category. More specifically, future work will compare the effectiveness of alternative MRLEs in the context of the same learning style. The author proposes to develop, validate and compare the alternative MRLEs selected for each specific learning style on the global continuum through tests of extent of learning transfer. MRLEs with the associated technological components such as interaction modality will be tested as course modules in existing units of study for measuring improved learning outcomes. The empirical determination of how particular MRLEs best support transfer of certain learning processes (constructive or analytical) through classroom experimentation. Then results will be generalized into guidelines for a design method for MRLEs to support complex and practical education methods.

REFERENCES


