Virtual Experiential Learning, Learning Design and Interaction in Extended Reality Simulations

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Abstract: Extended Reality (XR) covers both Augmented Reality (AR) and Virtual Reality (VR). How do we design immersive experiences in XR for teaching and learning? Immersive experiences are one of the unique virtues of XR simulations. A VR simulation can instantly teleport the user into a VR party or up on to the top of a building looking down. The experience immediately triggers sensory feedback and suspension of disbelief. Can theory about experiential learning support the design of VR and AR simulations for learning and the associated learning design? The article introduces three perspectives on successful design of game-based learning in XR. The first perspective is Virtual Experiential Learning inspired by Kolb's experiential learning cycle theory. The theory is applied to two illustrative examples: one in VR and one in AR. From an educational technology design view, the goal is to design digital encouragement for the potential transformation of the virtual experience into new knowledge: a knowledge ready to be applied in real life. Secondly, we propose that educational technology designers should develop ready-made learning designs to go with the XR applications. Learning design is a plan for facilitating the learning process in three steps: introduction, XR experience and debriefing. An effective learning design supports deeper learning and retention in the experiential learning process. Thirdly, in XR simulations, feedback is often unclear and navigation often unnecessarily complicated. We discuss how to improve interaction in the XR systems to support the immersive experience and the learning process. The paper is intended for designers of educational technology and game-based learning, practitioners and students in further education.

Keywords: Experiential Learning, Virtual Reality, Augmented Reality, Immersion, Design, Feedback, Interaction.

1. Introduction

Extended Reality (XR) and Mixed Reality are umbrella terms which include both VR and AR (Majgaard, 2017). They are expected to be widely adopted in classrooms and in industry in the coming years. What is important for educators to consider when teaching supported by XR, or for educational technology designers to consider when developing XR simulations? – and how can experiences in XR simulations be transformed into knowledge? This article presents learning perspectives on experiential learning in XR and on ready-made learning designs. It goes on to discuss how to support interaction in XR without losing immersion due to complicated interaction. XR and related technologies are receiving attention for their potential uses in education. One example is the Horizon Report, which found XR well suited to experiential education (Horizon Report, 2019). Through simulations and 360° video, VR and AR can enable learners to visit places they might otherwise not be able to access, such as museums and art galleries, the pyramids, a refugee camp, Mount Everest, or the Moon. XR enables learners to do things that are impossible in the physical world, such as manipulate entire environments or navigate inside veins and arteries. It may extend a dangerous reality, such as training for firefighters (Horizon Report, 2019).

One of the challenges in XR is the cost of head-mounted displays for every student in the classroom. Another is the availability or development of XR content fitting the specific curriculum. The didactical settings or learning design that support and direct the learning process may represent an additional challenge. Moreover, technical challenges may lie in technology which is not mature, or in XR applications which have not been properly user-tested.

In XR, the learner experiences virtual content and that experience is potentially transformed into new knowledge. Kolb's (1984) theory of Experiential Learning describes how learning happens as the learner reflects on concrete experiences – in this case experiences of extended reality.

In this paper, we propose three perspectives on learning supported by XR. The first involves the actual experience in VR and the situational interpretation seen from Kolb's (1984) perspective. Our second perspective describes the learning design, involving both introduction to academic knowledge, instructional guidelines for the XR experience, and debriefing afterwards. The third perspective focuses on technical challenges in the emerging XR applications. Seen from a user perspective, the interaction in XR simulations is often difficult. Pointing and clicking becomes a demanding task which must be rehearsed in a sandbox. The user also needs feedback on successful interaction or guidance on how to interact. Complex interaction and poor feedback lead to user disengagement and loss of immersion in the storyline.

Organisation of the paper: first, we introduce XR in teaching and learning. The Virtual Experiential Learning perspective is introduced supported by two illustrative examples. Then we introduce the idea of ready-made learning designs and, finally, a section on interaction without losing immersion.

2. About VR and AR in teaching and learning

VR in teaching and learning consists of the following four elements, often in combination:

- Static and dynamic visualisation of 2D and 3D-systems;
- Situated experiences, where the learner is immersed in a virtual story or situation;
- Interacting and creating objects in the virtual system;
- Seeing the unseen (Dunleavy, 2014).

VR uses computer-generated graphical simulation to create the illusion of participation in a virtual three-dimensional synthetic environment. The virtual experience is presented stereoscopically in a head-mounted display that senses head movements. Alternatively, the 3D experience can take place in a 3D cinema setting known as caves, which will not be discussed here (Sharp et al., 2019).

The VR experience via a head-mounted display is very intense (Murray, 1997). Murray likens the immersive experience to the enveloping sense of underwater diving – being surrounded by water and experiencing the world from this new underwater perspective. "The more a virtual immersive experience is based on design strategies that combine actional, symbolic, and sensory factors, the greater the participant's suspension of disbelief that she or he is 'inside' a digitally enhanced setting" (Dede, 2009). Immersion can be explained as a subjective impression that you are participating in a comprehensive, realistic experience. The sensors detecting head movements, combined with the corresponding movement in the digital simulation, support the situated immersive experience.

VR and AR are emerging technologies utilising mobile devices such as smart headsets, smartphones and tablets (Dunleavey, 2014). Where VR takes place in a virtual world, AR blends the physical and virtual environment (Dunleavy, 2014; Klopfer 2008; Milgram, 1994). This mixture can be illustrated as a continuum between physical reality and the virtual environment (see Figure 1; Klopfer, 2008; Milgram, 1994).

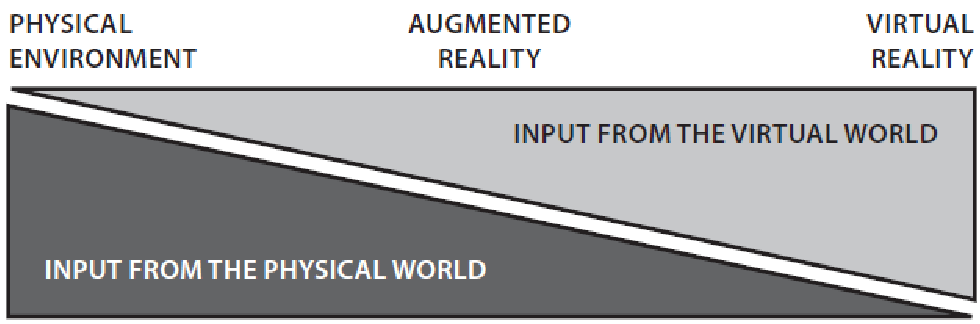

Figure 1: The continuum between the physical environment and the virtual world

3. Perspective 1: About Experiential Learning Theory and XR

How do we transform concrete experiences in daily practices and in XR into new knowledge? For over 35 years, Experiential Learning Theory (ELT) has been widely used in learning research (Kolb & Kolb, 2011). According to Kolb (1984), learning is "the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience". Experiential Learning Theory built on the foundational works of Kurt Lewin, John Dewey and Jean Piaget. Lewin's (1946) ideas on action research were based on repeating cycles of ideas, execution of actions and fact-finding reflections. The reflections led to new insights, new knowledge, new ideas and plans. Lewin's ideas have inspired management learning research, social sciences and learning design methodology (Majgaard, 2011). Kolb (1984) describes the actions as concrete here-and-now experiences followed by data gathering and observations of the experience. The analysed data and the conclusions are given as feedback in order to change behaviour in new experiences. Figure 2 depicts the four-step learning cycle. Immediate or concrete experiences are the basis for observations and reflections. These reflections are assimilated and distilled into abstract concepts from which new implications for action can be drawn. These implications can be actively tested and serve as guides in creating new experiences (Kolb & Kolb, 2011; Kolb, 1984).

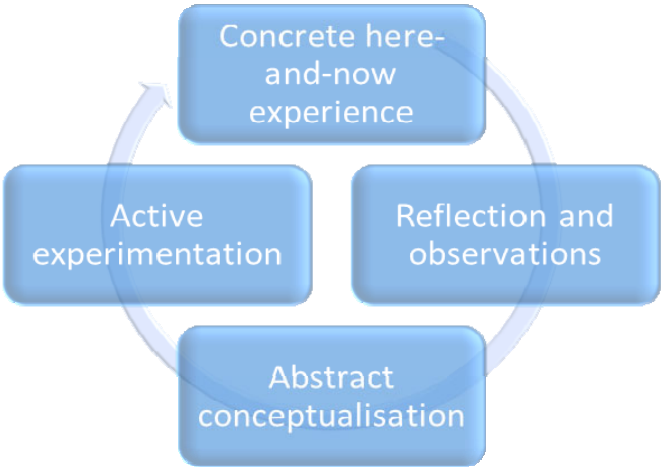

Figure. 2: Experiential Learning Model

Learning is best conceived as a process, not in terms of outcomes – a process where the learner receives feedback to support a continuing construction or reconstruction of experience (Dewey, 1929). As the learner reflects on her own actions and on feedback from the surroundings, new knowledge is assimilated and new behaviour emerges. According to Kolb & Kolb (2011), all learning is re-learning. Learning is best facilitated, in an iterative process that consider the learner's beliefs and ideas about a topic. The ideas can be examined, tested and integrated with new, more refined ideas. This ELT model is portrayed as an idealised learning cycle or spiral where the learner 'touches all the bases' (see the figure above). Learning derives from synergetic interaction between the learner and the environment. In our case, the VR application and the classroom are a part of the learner's environment.

3.1 Illustrative Example of Virtual Experiential Learning in AR

This example focuses on how AR can help students to translate two-dimensional computed tomography (CT) images into a three-dimensional understanding of the human hologram body (Nørgaard et al., 2019), see Figure 3 below. It is a complicated task for medical students to interpret 2D images and relate them to the 3D body. The background to the development of the application was an exploration of the 2D and 3D properties in AR HoloLens technology for teaching and learning. We were interested in exploring the potential and drawbacks of the HoloLens technology. Additionally, we wanted to support medical students' understanding of CT images.

Learning goal: To Improve medical students' understanding of two-dimensional CT scans by relating them to the full body shown as a three-dimensional hologram.

Content and learning activities

In the AR world, students saw a standardised hologram of a male body combined with selected 2D images from a CT scanner. The CT images were presented at the correct spatial positions in a hologram body (see Figure 3). The user could select which structures to show on or in the body (e.g. the skin, the vascular system, etc.) They could approach the body, go round it, study structures in detail and compare the presentation simultaneously with the set of CT images.

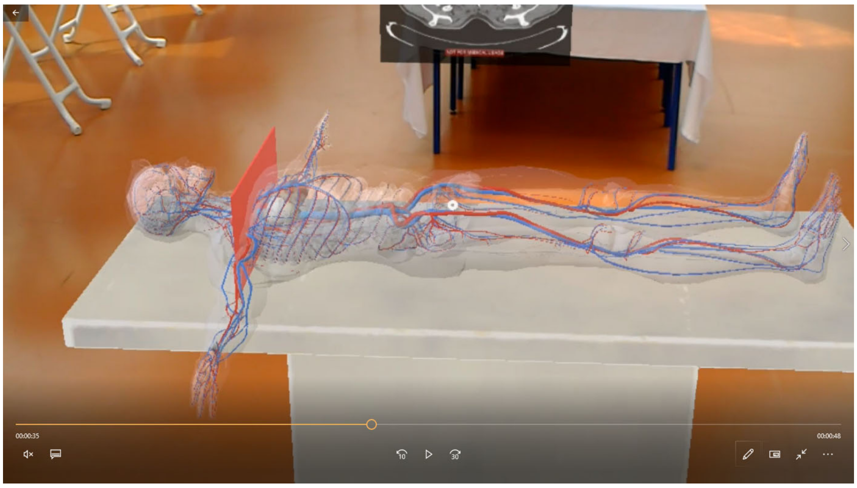

Figure 3: The hologram body and CT images could be seen through HoloLenses. In AR, it is possible to present and explore what is normally unseen to the naked eye or, as Dunleavy (2014) describes it: "seeing the unseen"

Reflections on Virtual Experiential Learning in the illustrative example

In the first stage - concrete experience, the learner physically experiences the here-and-now (see Figure 2). This experience forms the basis for reflection and the learner can consider what is taking place and decode it (reflective observation). The learner compares this to previous knowledge and tries to work out how to understand this (abstract) conceptualisation. After this, she can think about how to engage in an experiment, based on what she has learned, to improve what she has just experienced (active experimentation). Every new experiment is informed by previous experiences and reflections and forms a cyclical pattern that can be continued until the learner reaches her intended goal in this learning experience.

In the AR simulation, the students explored the relationship between 2D CT images and the 3D hologram human. The students experienced the similarities and the actual differences between 2D CT images of a shoulder, 2D CT images of a hip and the 3D hologram of the body (concrete experience). Shoulder and hip CT images were very alike - and it took experience to understand the differences (Nørgaard et al., 2019). The hologram image of the body enabled the students to reflect on the minor differences of hips and shoulders in the CT images (reflective observation) and this refined their understanding (abstract conceptualisation). This informed new cycles of experience and reflection (active experimentation).

3.2 Illustrative example of VR training in industry

Grundfos is a global company producing advanced water pump solutions (grundfos.com). Assembling pumps is a very complex task, mostly done by unskilled but highly trained staff. A key training challenge is efficient retention and redistribution of key knowledge. This requires consistent high-quality training of the staff, to equip them as well as possible for the tasks in hand. In close collaboration with Unity Studios, Grundfos has developed a VR training system (Unity Studios and Grundfos). The VR training system has been implemented at four production sites in Europe and Asia.

According to Grundfos, the VR training is very effective and has reduced training time and the number of malfunctioning pumps. The pumps were named correctly in the VR simulation and this helped staff to develop a more precise technical language. The lead in to technical discussions about production became exact and explicit.

Learning goals
The goal is to train staff by completing a series of virtual versions of physical installations of machines, assembling component parts, packing completed pumps and preparing them for shipment.

Learning activity
The training system was developed as a digital twin: a three-dimensional virtual copy of the physical installation (Unity Studios and Grundfos).

Ideal illustrative example levels in digital twin training with increasing levels of difficulty:
Level 1. In VR, the learner assembled simple pumps step by step.
Level 2. A simple production bug was introduced. The learner solved the simple problem.
Level 3. A more complex problem was introduced.

Reflection on learning aspects: cycles of expertise increased retention
The learners repeated the complicated steps at their own pace in VR until they mastered assembling a specific version of the pump without thinking too hard about it. Expertise is formed in any area by repeated cycles of the learner practising skills until they are nearly automatic, then having those skills fail in ways that oblige the learners to rethink and learn anew (Dreyfus & Dreyfus, 1986; Gee, 2001). Dynamic introduction of new challenges prompted the learners to think again and refine their knowledge. The repetition of old skills combined with new challenges increased the learners' retention. Elements of challenge of this type are also used in the world of computer games, where the player often repeatedly solves the same tasks but with new challenges (Gee, 2001). In computer games, challenges and skills are balanced. The balance changes a bit as levels are completed. In fact, both the digital challenge and the learner's skills increase. Cycles of expertise have great potential in XR simulation for learning.

Repeating the complicated steps with increasing levels of complexity can be compared to repeating cycles in the Experiential Learning Model. Increasing difficulty of challenges, interaction and feedback enrich the learning process. The figure below illustrates the three levels of activities in the VR simulation.

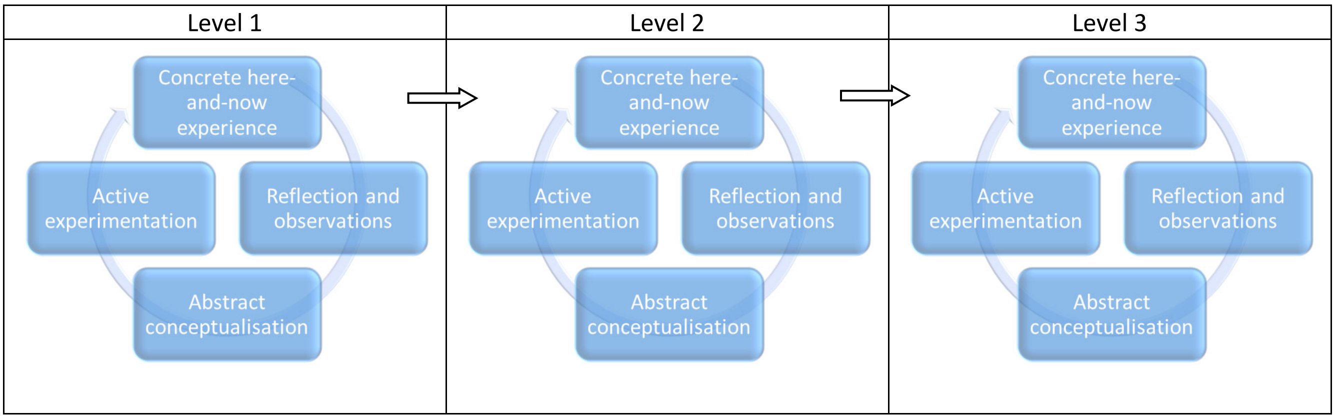

Figure 4: Three iteration levels in the Experiential Learning Model

4. Perspective 2: Reflections on ready-made learning designs

A huge problem in educational technology is the lack of good, simple ready-made learning designs. To optimise the students' learning process and reap the gains from XR simulations, the teacher/instructor must plan a learning design carefully 'around' the XR-simulation (Majgaard, 2019). Learning design is about planning, facilitating and conducting teaching in this case involving educational technology. It focuses on the activities learners need to undertake in order to meet the learning goals (Weitze, 2015). If the teacher is unfamiliar with the new educational technology (for example a simulation in HoloLens), it is difficult to plan and facilitate an optimal learning process for the students. This calls for the educational technology designer to outline simple learning designs to support the teacher to promote the success of the novel educational technology.

The XR learning design is essentially divided into three steps: introduction, XR experience and debriefing (see the figure below).

Figure 5: Phases in the XR learning design process.

Introduction: The usage of the XR simulations often calls for an initial introduction. The learner is often introduced to professional knowledge, learning goals and instructions on how to interact with XR application. Additionally, the teacher can also set the learner various challenges through the experiential cycle to improve expertise and to increase retention. In the AR example, instructions could be hints to recognise and identify anatomical structures on CT images of the mediastinum.

XR experience: The learners experience the simulation and explore virtual learning activities. A sandbox level is often the starting point of an XR experience if the interaction is tricky, e.g. exploring hand-gestures in the AR HoloLens equipment.

The XR experiences have previously been seen from the Virtual Experiential Learning perspective. XR provides the learner with experiences that can be compared with tacit knowledge. The concept of "tacit knowledge" covers knowledge that is unarticulated and linked to the senses, motor skills, physical experiences, intuition, or implicit rule of thumb (Nonaka et al., 2009). For example, the VR experience is linked to physical experiences – since the learner interacts with head movements and involves the seeing and hearing sense.

Debriefing: The teacher directs a debriefing and evaluation of the virtual experiences, see figure 5 above. The retrospective discussions of the experience in XR can promote the learning process. For example, tacit knowledge can be transformed into explicit knowledge and provide a rooted understanding of the topic.

Based on the whole process and on the debriefing, the learning design plans are likely to be updated for future teaching.

The goal of the XR learning design model is to plan how best to assimilate concrete experiences into new knowledge, whether tacit or explicit. Essentially it is the instructor/teacher who develops and executes the overall XR learning design. The designer of the XR experience must foresee, user-test and recommend a typical learning design to convey optimal learning processes for the learners.

In some XR simulations, challenges and quizzes are built in to support the learning processes. In other cases, the simulations are more open- ended and explorative. The latter call for customised and precise learning designs.

5. Perspective 3: Interaction without losing immersion

In this section, we introduce challenges in the design of XR simulations for learning regarding interaction and feedback. If the interaction does not work properly, it both affects the learning design and leads to reduced learning outcomes. Immersion and smooth interaction in the XR simulations are a crucial foundation for virtual experimental learning processes. Technical difficulties might destroy both the learning process and the XR experience!

Interfaces, if designed poorly, can make users look stupid or feel insulted (Preece et al., 2016). The effect can be to annoy and frustrate them to the point of skipping the simulation. Many situations cause such emotional responses. Examples are: no immediate response when a button is clicked; when the user is required to carry out too many steps to perform a task; or over-use of text, animations and sound effects. In XR, a poorly designed interface makes the users feel frustrated and lose the feeling of immersion.

In XR, there is not yet a customary way to point to and click on an interactive object. In HoloLenses you interact with hand gestures, for example precision grip for clicking on an object. Users are recommended to practise gestures before anything else.
HTC Vive and Oculus Quest have two controllers each with several buttons and built-in accelerometer. Each developer decides how point and click works in their application. I tried an impressive application imitating a person with Alzheimer's. Unfortunately, the pointing and clicking in Alzheimer application was too complex – the user pointed the controller in a given direction and at the same time decided which way to turn the avatar, using a thumb-operated joystick button. The teachers had to make the students practise in a sandbox before entering the Alzheimer's simulation. In the sandbox, the students learned the complex interaction.

In Google cardboard applications, GazeClick is a simple way to direct the cursor based on orientation of the user's head. Given proper feedback from the system, this is a simple way of interacting. In a VR and alcohol example, GazeClick was used optimally (Lyk et al., 2019; Majgaard, 2018). The user simply needed to point at an interactive object for a few seconds. Development of the clicking procedure needed some adjustment to provide the necessary feedback, which communicated that the click was successfully in process. Initially the system did not provide the necessary feedback. Usability testing was crucial for fine-tuning the system taking the user feedback into account. Furthermore, originally the pointer/cursor was so small that the users overlooked it. So a good piece of advice for the educational designer is to usability-test the interaction thoroughly when it comes to XR devices.

6. Summary and conclusion

In this paper, we have introduced three perspectives on how to promote successful design of educational technology or game-based learning in XR.

The first perspective was about the Experiential Learning Theory model applied to two illustrative XR simulations. The model described how the here-and-now experiences gradually became new knowledge when the learner interpreted the XR experience. This was followed by active experiments and new experiences. The experiential learning model can support the educational technology designer in planning and developing specific XR activities, and not only virtual worlds to explore. In the VR example, repetitive cycles of expertise were introduced in form of increasingly challenging levels. Each cycle of expertise in the XR experience reflected a cycle in the experiential learning model system.

Secondly, we proposed that educational technology designers should develop and test ready-made XR learning designs. The XR learning design supports learning processes and helps the learners' gain tacit knowledge from their experiences in XR. Fundamentally, the XR learning design model consists of introduction, XR experience and debriefing. The instructor/teacher present could be new both to the XR technology and to the specific application. Teachers/instructors would benefit from ready-made, professionally developed XR learning designs. The success of the XR application therefore depends on ready-made XR learning designs. The teacher/instructor would ideally also need to customise the ready-made learning design to fit the specific target group: in other words, business as usual.

Thirdly, we discussed how the system should provide feedback during interaction with the simulation, in order to preserve immersion. Yet, there is no consensus on how to "point and click" in XR, as with the computer mouse. The designers of XR simulations should provide simple click-and-point solutions in order to avoid information overflow and ideally provide possibilities to train this in the first minutes of the XR simulation.

The immense advantage of using XR simulations in teaching and learning processes is the immersive here-and-now experience that potentially deepens students learning processes and helps new knowledge to take root.

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