Embedding Virtual Objects Into the Physical World

Student-Centred Augmented Reality Concept Design and Development

Ari Alamäki and Amir Dirin

In the contemporary world where almost, everything has moved towards digitalisation, the combination of virtual and physical worlds has proved to be an efficient approach in an educational context. Since the application of augmented reality (AR) and virtual reality (VR) in education is on the rise, we recommend a conceptual framework for technology education. However, little is known about how students mix virtual and physical objects in solving everyday problems through prototyping and envisioning the potential solution. This study is based on the gathering and analysis of qualitative and quantitative data on students in higher education. In the first study, we collected (N = 100) information about potential problem-solving contexts for augmented and virtual reality applications. In addition, this study examines student (N = 62) projects in the AR and VR fields to generate new knowledge about co-creation activities in design processes. The results reveal that when students design and develop virtual objects in connection to the physical world, they learn more than just using digital technology alone. Combining the virtual with the physical world provides an extensive learning environment not only for digital problem solving but also for materialistic and physical surroundings. This paper contributes a new theoretical understanding for academicians about the role of AR in technology education and a conceptual framework for practitioners to enhance student learning through AR-based design projects.

Keywords: Augmented reality, Higher education, Technology education, Pedagogy, User-centred design

Introduction

Virtual objects are becoming a more integral part of physical objects (Porter & Heppelmann, 2015; Yilma, Panetto & Naudet, 2019). Cars, buildings, furniture, robots, toys and various devices have digital extensions and solutions. The physical man-made world is evolving towards a virtual–physical world. Thus, it is important to research pedagogical practices and experiences regarding how students could learn to design and develop projects for which they mix virtual and physical objects (Tönnsen & Schaubrenner 2017; Vartiainen et al. 2020). In this study, we examine this phenomenon from the perspective of augmented reality (AR) applications as they are technologies that enable the integration of the virtual and the physical. In addition, there are easy-to-use AR content management systems for creating AR applications without the need to programme software code.

Although there is a long history of digital solutions in design and technology education (e.g. Järvinen, 1998), this study provides new understanding about the design and development of AR solutions, not only about using them in educational settings, First, this study aims to fill this research gap by surveying students' thoughts related to opportunities for AR and virtual reality (VR) applications in different sectors. We want to deepen our understanding of a problem-solving context in which augmented virtual reality technologies could provide value from a student perspective. Second, we investigate co-creation activities in design processes by using case examples of student projects in higher education. Thus, this study presents student projects for which they have adapted AR technologies to the education and tourism context to learn about mixing digital and physical worlds. The results provide new knowledge

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for teachers and teacher educators to consider when choosing the proper pedagogical models with which to combine the virtual and physical worlds in design projects.

Theoretical background

Augmented reality refers to the combination of a real environment with digital information (Kipper & Rampolla, 2013). Virtual reality is defined as a three-dimensional (3D) computer-generated virtual environment in which a user can become immersed and interact with an object (Bowman and McMahan, 2007). Both have become alternative technologies for various purposes in contemporary life, making the combination of virtual and physical environments possible. The combination of digital and physical worlds has brought many opportunities in various sectors from education and entertainment to industry. Education is one of the sectors in which AR and VR are proving to be the most valuable (e.g., Laine et al., 2016; Nguyen et al., 2018).

Designing and developing AR and VR applications requires pedagogical, technological and user experience understanding. Prior research (Dirin & Laine, 2018; Saballe et al., 2018) shows that the design of AR and VR solutions includes design challenges from the user experience perspective that need to be overcome. AR creates surprising and rewarding emotional experiences for students as it is capable of generating unexpected positive experiences (Alamäki, Dirin & Suomala, 2021). However, AR and VR applications are often more complicated to use than traditional web pages and mobile applications. Users need to download an AR application, and they need to be able to scan the target image to launch the AR content on a mobile screen. VR applications require the use of VR headsets on which users need to be able to click on the right VR mode in 360-degree videos. The main design challenges from the technological perspective include how to transfer from a low-fidelity prototype (2D) to a high-fidelity prototype (3D) in the design processes. It is difficult to visualise the final 3D-based user experience without 3D visualisation, and creating an AR application with AR content managers requires technical skills in terms of content management systems and/or programming skills. However, the most important perspective is associated with pedagogical methodologies. This covers design challenges on how to ‘steer’ students’ cognitive thinking and affective feelings so that they will be able to construct new meaningful knowledge and learning experiences. It is very much about the creation of learning situations in which students can build proper relationships with the augmented virtual content in connection with the physical world.

Prior research (Clark 1994; Fiorella & Mayer, 2016) shows that there is no direct causal connection between a digital environment and student learning. Digital media do not directly lead to learning, but they deliver audiovisual cues, messages or stories that students interpret based on their inner mental schemas. Thus, cognitive observation or the use of digital content may affect student learning depending on the cognitive and affective responses of students’ mental processes. This is called the media effect whereby digital media transmit audiovisual information that influences students’ cognitive thinking or affective orientation, causing changes in their orientation, behaviour or interest in certain issues, phenomena or objects. Thus, a digital medium by itself does not cause a learning effect, but it can occur through the interaction between students and the digital environment. The relationship between the content and receiver creates the media effect, but the content by itself does not (Watzlawick, Beavin & Jackson, 1967). In other words, the quality of the interaction between AR-application and student enables a learning experience if the interaction triggers cognitive, affective or behavioural changes in students’ mental models.

Conceptual framework and research questions

The conceptual illustration in Figure 1 shows the key elements of mixing the virtual and physical worlds to enhance user experiences. The use case illustrates an example in which students could mix the virtual and physical by creating a physical device or system to simulate industrial use and AR-based instructions for effectively learning to use it. The AR application (virtual object) presents a video that helps a potential user to use the device or system (physical object). The instructional AR application opens when a user scans the target image of the physical device or system with the mobile AR application. Thus, the virtual object is an extension of the physical object through the creation of value for the users and other stakeholders of the device or system in the specified problem-solving context.

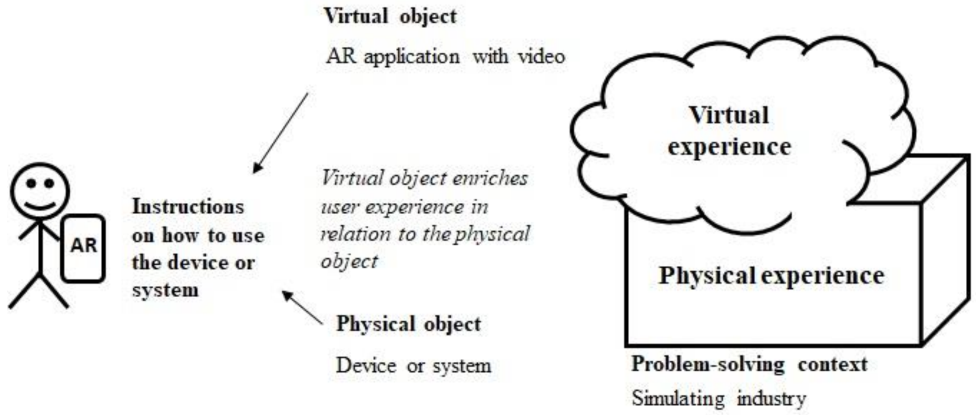

Figure 1. An example of how students can mix virtual and physical objects in learning projects.

This study examines students' ideas regarding opportunities for AR and VR applications in different sectors. Additionally, this study investigates co-creation activities in design processes by using case examples of student projects. Thus, the study seeks to answer the following research questions.

1. How do students perceive opportunities for AR and VR (Study 1)?
2. What co-creation activities lead to AR design and development (Study 2)?

Methods

Participants and research method

To answer the first question in Study 1, we employed a quantitative data gathering technique through a questionnaire that included one open-ended question to determine possible contexts in which AR and VR would fit best based on the participants' personal experiences in the experiment. The participants in the Study 1 experiment were 100 undergraduate students (39 female, 61 male) in Finland. The students were between 21 and 30 years old. Data were collected between 2016 and 2018. Students had already experimented with the AR and VR applications before they answered the following open-ended question: '*If you compare your AR and VR experiences, where would they be best suited?*' To answer the one research question in Study 2, we analysed eleven students' (N=62) design-and-develop projects, in which they had to analyse, ideate, design and develop AR solutions that solved real-life user or business problems. The students in Study 1 and Study 2 were from different classes, but all of them had competencies and knowledge in digital business or digital service design and development courses in bachelor's degree programmes.

The research methodology chosen for this study was an abductive qualitative study as it contributes conceptually to the debate on pedagogy in design and technology education. An abductive qualitative research approach (Dubois & Gadde, 2002) enables the researchers to build a conceptual model while analysing the data in an iterative manner. In this research model, the researchers simultaneously process previous literature and analyse empirical data (Dubois & Gadde, 2002). Thus, in Case Study 1, we analysed data quantitatively, whereas in Case Study 2 we deepened our understanding qualitatively.

Research design and procedure

The experiment in Study 1 took place in classrooms, where each participant (*N*=100) used AR and VR marketing applications. The researcher handed out the written instructions for the experiment, which included the test content and steps required to conduct the experiment. The students downloaded an Arilyn application (arilyn.com) to their smartphones to launch the AR application. The AR application presented an interactive 3D cat, which was part of a marketing campaign for a local dairy farm. The instructions for the application were shared on the milk cans of a dairy farm, and the users were able to play with the 3D cat on the screens of their own smartphones. VR applications were 360-degree sports videos that seventy percent of students watched using VR headsets, and others without VR headsets. The students answered the study question after using the application. In Case Study 2, we described two student project cases in higher education for which the study participants designed and developed an AR application to enrich the user experience of the physical surroundings. Each student group created a report in which they described the design and development of an application. In addition to this, they gave a presentation during which the teachers wrote notes for evaluation purposes. We have used these materials as evidence of co-creation activities in the design and development phases. The researchers also participated by playing the roles of teachers in the related courses. Thus, the study also contains elements from the action research (Brydon-Miller, Greenwood & Maguire, 2003).

Data analysis

The research approach chosen for the data analysis was a qualitative case study to allow for a deep study of real-life phenomena in higher education (Gummesson, 2000). The literature review facilitated an understanding of students' experiences and responses. The open coding of answers allowed for the construction of categories according to student responses. Open coding was applied without predefined coding categories according to the qualitative analysis of open-ended questions (Strauss & Corbin, 1998). The coding of open-ended responses in the questionnaire involved marking all comments and noting or explaining where AR and VR could be applied. The analysis showed that students reported similar terms and contexts, which allowed for the construction of common categories.

The theoretical understanding of the empirical findings of the AR context and design activities were constantly revised (Gummesson, 2000). In analysing the data from Study 1, the focus was on the adoption context of AR. In the second data analysis phase in Study 2, the design activities were identified, reviewed and classified according to the coding of themes (Strauss & Corbin, 1998). The interactions between the conceptual framework and the empirical evidence were used to increase the trustworthiness of the findings. The qualitative analysis could present weaknesses in the interpretation of empirical findings (Eisenhardt & Graebner, 2007). Thus, the findings were reflected within the conceptual framework of the interrelationship between the empirical evidence and the theoretical literature. Furthermore, using two case studies increased the trustworthiness of the interpretations and conclusions.

Results

Study 1: How would students like to adapt AR and VR technologies?

Study 1 aimed to increase our knowledge of the students' understanding of opportunities to adapt augmented and virtual reality technologies for different sectors. Thus, it aimed to increase our understanding of the students' preferences towards the adoption of AR and VR. After the hands-on experiment, during which the students used both AR and VR applications, we asked them to list sectors into which they think the technology that they just used could fit best. Table 1 shows the results.

Table 1. Student opinions about the contexts into which the technology could fit best.

Contexts into which students think that AR or VR technology could fit best	**Augmented reality** (interactive augmented 3D application)	**Virtual reality** (360-degree videos with VR headsets)
Playing games	11 (20%)	22 (22%)
Education	10 (18%)	10 (10%)
Advertisement	8 (15%)	8 (8%)
Entertainment	4 (7%)	8 (8%)
Tourism	2 (4%)	14 (14%)
Construction	0 (0%)	11 (11%)
Other	20 (36%)	29 (28%)

Some students gave sector examples only for AR or VR technology, whereas others listed sectors for both AR and VR technologies. The results show the student opinion that both AR and VR could fit as a technological enabler for games. It is an interesting finding that educational applications, namely for learning and teaching purposes, were seen as the second significant adaptation area for AR, but not for VR. According to the student opinions, VR technologies could fit best for games, tourism and construction, followed by education. The students found it easier to identify adaptation sectors for VR technologies than for AR. The findings point out that AR as a more interactive technology could fit better for educational purposes than VR. If we combine games and entertainment, which belong to the same group from the value creation perspective, we see that both AR and VR provide enjoyment value for users.

Study 2: Empirical experiences from student AR projects in higher education

In the first case example, the task of 10 student groups (N = 59) in Digital Business and Digital Tourism Service courses (we mixed information technology and tourism students in the groups) was to design and develop an AR application for use in tourism. Thus, the goal for the students was to ideate, design and develop a virtual object that presents additional information about a physical object located in a tourism destination. In practice, the business goal was to create an AR application that provides new audiovisual information for tourists visiting the location. For example, two student groups designed and developed an AR-based game that shares location-specific information; other groups created an application that showed historical information about the physical location. The design process started with situation analyses (e.g. *"...service does not meet the expectations of tourists"*), defining objectives (e.g. *"…would tell more information about..."*), users (e.g. "*we decided to select domestic visitors as the target group…"*) and problems (e.g. *"…AR-technology…"*) and it extended to project planning. It continued with the selection of the physical object to 'digitalise' and its relevant informative content in order to create additional value for users at the chosen location. After that, the students began creating the concept plan that they finally concretised, developed and tested by using an Arilyn AR manager, which enabled them to develop real AR applications. In the report and presentation, they detailed and reflected their design and development experiences.

In the second case example, three higher education students (N = 3) in Digital Service Design course designed and developed an AR and VR application. Their task in the assignment was to study opportunities to integrate both AR and VR into the physical natural environment. The project phases are reported in the students' final report (see Saballe, Lemmi & De Oliveira, 2018). This project also provides evidence that mixing the virtual and physical environment is an innovation process wherein students adopt a user-centred design approach. They started with the user study phase, wherein they collected data by interviewing users and experts as well as creating user profiles along with scenario planning and requirements. After this, they created a concept and a prototype, and then they implemented digital applications and tested them.

Discussion

We aimed to draw a conceptual framework within which to theorise phenomena whereby virtual and physical objects are mixed to enrich learning experiences. It provides a comprehensive learning environment for students in design and technology education. First, we analysed students' understanding about opportunities to use AR and VR technologies in design and development projects. Second, we reviewed students' real-life projects for which they designed and developed AR applications.

The first research question concerned perceived opportunities for AR and VR technologies. Based on students' hands-on experiences with AR and VR applications, the students listed playing games and education most often as adaptation opportunities for AR and VR technologies. Tourism and construction were mentioned often for VR adaptation, unlike AR. In tourism and construction, VR enables the creation of virtual experiences related to remote locations and unconstructed building or surroundings. The results show that students see the most significant value in gamification and education, which enables the creation of digital objects that provide learning opportunities for users. For example, students can design and develop physical objects along with instructions for using AR technologies. The physical objects could be artefacts such as devices, systems, decorative items or furniture. The user scans the physical object and an AR application opens the digital instructions on the screen of a mobile device.

The second research question concerned the co-creation activities that lead to AR design and development. Based on the analysis, we defined co-creation activities during which students design and develop AR applications to create virtual–physical solutions. The design of virtual objects and the design of physical objects do not differ from each other from the process perspective in general level. Both begin from an understanding of current situation, objectives, user needs, profiling users and evaluating requirements from different stakeholder perspectives, which has long been the main priority of designers (e.g. Alamäki & Dirin, 2015; Gould and Lewis 1985; Norman 1986). Concept planning refers to innovation practices that are comprehensive student actions in terms of learning and teaching, covering several cognitive and affective learning outcomes (see e.g. Hero, Lindfors & Taatila, 2017; Lindfors, 2010). Designing, prototyping, developing, evaluating and testing are co-creating activities whereby students develop various knowledge dimensions, especially in social interaction within student groups as well as with external experts and teachers (e.g. Alamäki, 2017). Reflecting on experiences is also an important phase in mixing virtual and physical objects that happens often in reporting, presenting and demonstrating results for other students, families and teachers. Pedagogical methods define the way students work and learn, as well as what kinds of learning goals and activities are included in projects.

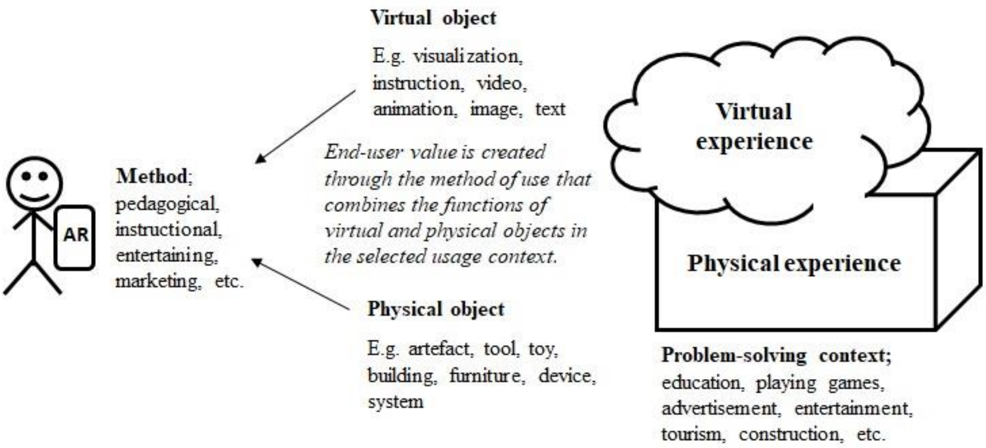

Figure 2. Factors affecting the design and development of AR in student learning projects.

Based on the findings of studies 1 and 2, we determined that students need to make several decisions in defining, designing and developing AR solutions (Figure 2). A virtual object may consist of various media elements, and a physical object can be practically any man-made or natural material object; the problem-solving context varies by sector (from an educational context to tourism and entertainment). However, the user perspective is the most important factor when mixing virtual and physical objects to solve problems in the selected context. Thus, it deals with the methods through which students as designers aim to create the process of how, where and why the user will use the AR application. The chosen method combines the roles of virtual and physical objects in relation to the selected usage context.

Our study aligns with prior design and technology studies (e.g. Järvinen, 1998; Lindfors, 2010; Rasinen, 2003) that show that innovating and creating solutions is a more effective method to learn about the virtual and physical worlds than just using solutions or reading books. The results show that when students design and develop AR solutions, they learn much more than just using AR (Figure 3). If students are using AR, their cognitive outcomes primarily focus on the cognitive activities of remembering and understanding. Our students' projects show that when students design and develop AR, their cognitive outcomes extend to analysing, synthesising, evaluating and creating activities in different contexts.

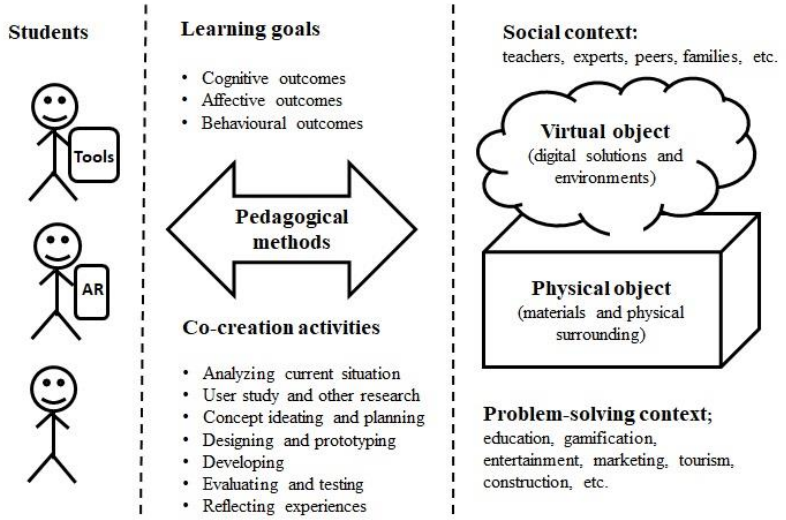

Figure 3. The conceptual framework for embedding virtual objects into physical objects in a student learning environment.

Helping students develop competence for mixing the virtual and physical worlds by working on practical projects proved to be a very efficient approach. The resulting AR applications demonstrated that the students were enthusiastic to continue their competence development further in this field. Despite many challenges, such as a lack of prior knowledge and skills in the AR-development environment, the students' self-motivation to learn was seemed to be higher than in many other courses. Thus, we conclude that AR brings an effective motivational element to virtual–physical design projects.

Limitations and future research

This study has several limitations. First, the students used the applications for quite a short period in a laboratory-type research setting in Study 1. Second, the Study 2 used quite a small target group in the case examples, which limits the generalisability of the results. Third, the results are descriptive findings. However, this study points out the preliminary findings how students can learn to embed virtual objects into the physical world through comprehensive AR-based learning projects. Thus, the students' actual innovating and problem solving processes in mixing virtual and physical objects merits further psychological examination. More research is also needed on pedagogical practices in real classroom experiments.

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