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RESEARCH PAPER

Using Augmented Reality for Teaching

A Hands-on Seminar Concept to Enhance Acceptance in Future Teachers

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ABSTRACT

In tandem with the development of more effective and convenient Augmented Reality (AR) solutions for teaching, digital development programs aim at providing the infrastructure to include digital media in classrooms. To prepare future teachers for the demands of digitized learning settings, adequate university courses are needed to enhance digital competencies. Based on such theoretical models as the Technology Acceptance Model (TAM), the Unified Theory of Acceptance, and the Use of Technology Framework (UTAUT), this paper seeks to enhance not only the preparedness, but also the attitudes, of future teachers toward incorporating and disseminating AR solutions into their teaching scenarios and institutions. Focusing on instructional design principles and the aim to create a meaningful teaching scenario that can be integrated into the curriculum, the paper develops a seminar concept for master's students in educational sciences. It contains a theoretical framework for using AR for teaching, a hands-on conceptualization, and a joint exploration of the finished solutions. The current paper presents the concept of the seminar, first evaluation results, lessons learned, and development directions with a focus on the education of future teachers.

1 Introduction

In recent years, the capabilities of Augmented Reality (AR) in education have steadily advanced, with the availability of easily implementable and affordable (if not free) solutions progressing consistently (Akçayır & Akçayır, 2017). Simultaneously, comprehensive concepts have been devised, particularly since the onset of the COVID-19 pandemic, to promote the use of digital media in schools and other educational institutions. On the one hand, funds have been allocated at the infrastructure level to equip educators and learners with digital devices, establish widespread Wi-Fi access, and implement technical support structures. On the other, based on such scientifically-grounded models as DigCompEdu (Redecker, 2017), efforts have been made to advance the curricular integration of teaching with the reflected and targeted use of digital media.

However, recent studies have found that, due to both internal and external barriers, educators often use new, more complex digital media only to a limited extent (Xie et al., 2023), and tend to mainly rely on the media available during their own education experiences (Gittinger & Wiesche, 2022). Hence, there is a need to facilitate engagement with digital media in the curriculum. Beyond mere usage, adequate seminars and university courses are necessary to prepare aspiring educators for the requirements of digitized learning arrangements. The focus here should be on promoting digitalization-related competencies that enable the pedagogically-meaningful, non-technically determined planning of lessons involving digital media.

This article introduces the planning and implementation of a practical hands-on seminar, where students independently plan the use of AR in their own teaching, compile content, and subsequently test the results. The seminar seeks to not only enhance digitalization-related competencies, but also to emphasize the acceptance of using AR in one's own teaching. This approach aims to enable and encourage a pedagogically-reflective integration of AR in teaching. It is our hope that this contribution will provide researchers and educators with insights for the further development of teacher education especially, but not limited to, the university level.

2 Theoretical Background

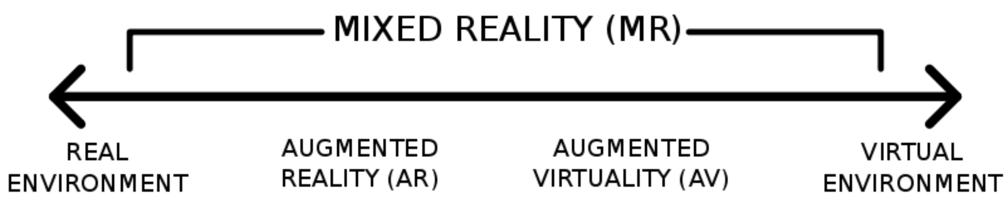
The In the theoretical part of this article, we first describe AR and its characteristics, before delving more deeply for its use within teaching and learning (with an emphasis on higher education teaching). Subsequently, we present the theoretical model used to empirically investigate the benefits of AR technologies in higher education teaching.

2.1 Augmented Reality

As a component of Extended Reality (XR), AR provides a real-time overlap of physical and virtually-created elements that can be added to the real world. This ranges from overlaying simple supportive lines in camera perspectives for sports or driving to the integration of interactive, complex 3D elements (Rauschnabel et al., 2022). These possibilities for enriching the physical world have undergone extensive developments in industry, commerce, and education. The widespread adoption of AR has been significantly facilitated by the interplay of low technical requirements and broad application possibilities (Dunleavy et al., 2009; Sommerauer & Müller, 2018).

To contextualize AR within the broad spectrum of XR offerings, various models have been proposed, including Milgram et al.'s (1995) Mixed Reality Spectrum. On a linear continuum from the *real* to the *virtual* environment, the influence of physical elements gradually diminishes and is replaced by virtual elements (see Figure 1). AR primarily represents physical content, with Augmented Virtuality (AV) as the next stage incorporating mainly virtual environments augmented by physical elements.

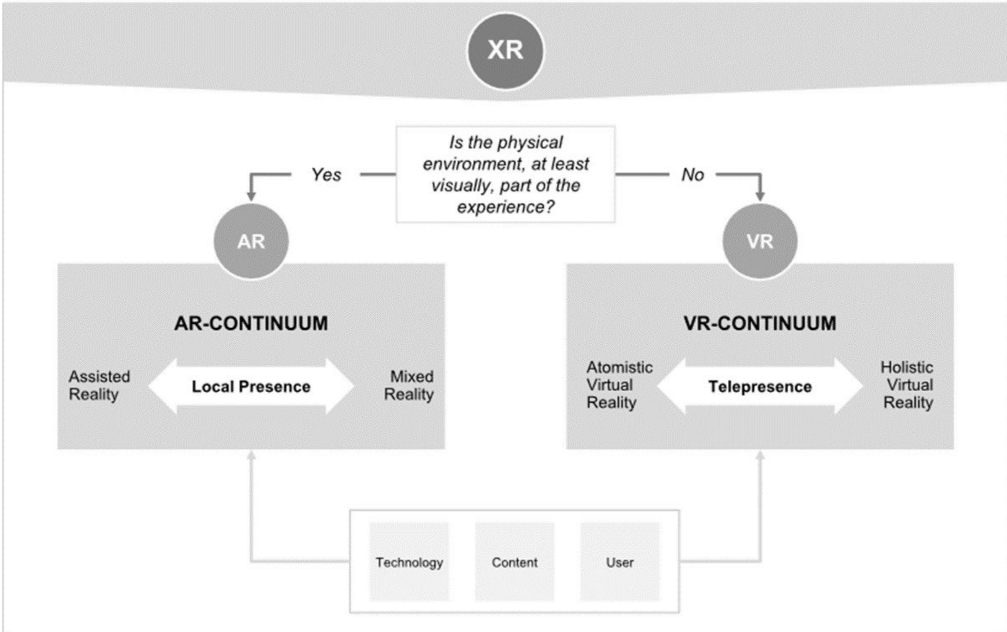
Figure 1: The mixed reality continuum (Milgram et al., 1995)



A drawback of various models, including Milgram et al.'s (1995), is the wide array of different techniques and contents that fall within this spectrum, making the classification ambiguous. Indeed, AR is categorized differently in various publications, and is occasionally even subsumed under VR. Therefore, the XR model developed by Rauschnabel et al. (2022) is employed to provide a clear differentiation of AR from other virtual settings. This model achieves clarity by posing the question, "Is the physical environment, at least visually, part of the experience?" (Rauschnabel et al., 2022, p. 6). If answered positively, the technology is attributed to AR. Further classification then occurs within a closed AR continuum (see Figure 2).

The AR environment combines AR-devices, -enablers, and -displays. Examples of such AR applications range from added lines in sports broadcasts and parking assistance to the overlay of entire machinery in production halls. More specific examples include the augmentation of additional content in art exhibitions, 3D representations of components based on 2D drawings, or the presentation of animals in specific locations as part of an exploration task (Rauschnabel et al., 2022).

Figure 2: XR overview and categorization by Rauschnabel et al. (2022)



2.2 AR in Education

Technological advancements in society and daily life influence education in two directions. On the one hand, these new possibilities enable the integration of technology into teaching and positively impact learning processes. On the other, technological development necessitates the transformation of teaching to address the requirements of everyday life, particularly in the educational context (Kerres, 2020).

Despite the emergence of AR in the 1990s, research on AR in education has a relatively young history within educational research. With the growing technical availability, its broader use in education is expected, accompanied by an increased focus on its underlying effects (Akçayır & Akçayır, 2017). Particularly when compared to the challenges posed by VR, AR presents fewer obstacles for institutions and educators. The interactive, context-specific, and collaborative elements of learning with AR are highlighted as opportunities (Dunleavy et al., 2009). However, while development is certainly progressing, the research landscape regarding teaching competencies and good-practice examples remains dispersed (Klimova et al., 2018). Indeed, there are clear gaps in the literature regarding teaching aspects related to AR, thus emphasizing the need for more comprehensive exploration. Moreover, implementation guidelines and best practice examples for using AR in the classroom remain somewhat scarce (Buchner et al., 2023). Therefore, pedagogically-meaningful AR learning scenarios that follow instructional guidelines and transcend mere technology usage are urgently required.

Existing research on the advantages of AR in education has particularly emphasized its positive effects on individual learning outcomes. This includes improvements in academic achievement and learning motivation, along with the ability to assist learners in understanding new content. On a pedagogical level, there is evidence of increased engagement with content and a heightened interest in the subject matter. Recent research has highlighted students' improved cognitive engagement in AR-supported activities (Wen, 2021), as well as how learning outcomes can be enhanced through increased active engagement, participation, and exploration (Volioti et al., 2023). Furthermore, significant attention has been paid to the potential of the 3D visualization of objects that were previously only displayed in 2D (Rizov & Rizova, 2015). AR can be used to visualize complex 3D objects and shapes in order to help students understand spatial configuration (Hidayah et al., 2022). However, this also reveals an exemplary discrepancy in the existing research results: Based on the level of learners' spatial abilities, the ability-as-compensator hypothesis suggests that the additional information provided by 3D representation supports learners with lower spatial abilities. In contrast, the ability-as-enhancer hypothesis posits that the additional information may overwhelm learners and require well-developed spatial abilities, thus providing greater benefits to those with existing advantages (Krüger et al., 2022). Overall, there are varying research findings regarding cognitive load when using AR (Akçayır & Akçayır, 2017).

However, AR's negative effects have also been reported. Students face several difficulties in handling AR technology. For example, using AR seems to be cognitively demanding. Despite the inconclusiveness of certain research findings, several scholars have argued that AR learning and training applications provide too much information and more distracting factors, such as the devices used. Consequently, there is a risk of heightened cognitive overload that should be considered when using AR for learning purposes (Akçayır & Akçayır, 2017; Buchner et al., 2022). Furthermore, from the perspective of instructors, vast quantities of time are needed to teach students how to use and prepare for the implementation. Simultaneously, concerns have been raised about the insufficient experience of educators in dealing with the technology. Additionally, there are reports of teachers expressing worries about relinquishing control over students' actions when using AR (Dunleavy et al., 2009).

2.3 AR in Higher Education

In the realm of higher education teaching, a contrasting scenario emerges in relation to technological developments. Despite the availability of technological innovations and artificial intelligence, traditional teaching and assessment formats persist (Klimova et al., 2018). Considering the perspective of learners in teacher education, it is unsurprising that familiar technologies continue to be employed in teaching, and that the previously-mentioned challenges emerge from educators' insufficient experience with technology.

To address these challenges, hands-on seminars are designed to foster experiential learning and knowledge exchange. These seminars focus on the independent conception and exploration of digital teaching environments within protected settings. This approach aims to facilitate both the acquisition and sharing of experiences among educators and learners, providing a practical path to overcoming barriers related to the use of technology in teaching.

2.4 Use of AR in Higher Education

Against the backdrop of technological advancements in society and the imperative to equip prospective teachers for independent use of AR while considering pedagogical implications, two aspects are combined: A structured model of the professionalization of educators' competencies and a model highlighting core aspects regarding technology acceptance.

Concerning the professionalization of educators, the "integrative model of digitalization-related competencies" (Borukhovich-Weis et al., 2022) serves as the basis. This model draws from various frameworks, such as the Technology, Pedagogy, and Content Knowledge (TPACK) model (Koehler et al., 2013) and the DigCompEdu model (Redecker, 2017) at the European level, and others to comprehensively illustrate the different aspects and dimensions of integrating digital media in education from a teacher's perspective. The integrative model aids students in reflecting on the diverse facets of their professional development.

For the implementation of the concept and the accompanying research within the current article, focusing on acceptance, we used the aforementioned TAM (Venkatesh & Davis, 2000). This model provides a basis for understanding the factors influencing the acceptance and adoption of technology, offering insights into the attitudes and perceptions of educators toward incorporating digital tools in their teaching practices.

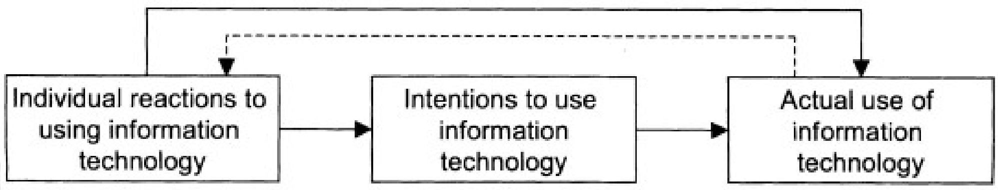
2.5 Technology Acceptance

With teachers playing a key role in the process of integrating and accepting digital media in education (Tzima et al., 2019), the internal barriers (Xie et al., 2023) must be specifically addressed. While the use of AR in education and its influence on learning has been well researched (with many positive effects having been found), scholarship on the acceptance of AR is lacking (Dalim et al., 2017). Dalim et al. (2017) highlighted the need for design choices catered to educator's expectations to improve acceptance, while Tzima et al. (2019) underlined cooperation and support as parts of the general embedding of AR in the overall processes.

2.6 The Technology Acceptance Model

This theoretical framework broadly outlines the relationships between user acceptance and use during the adoption of new technologies. It is based on the underlying idea of user acceptance models, which state that individual reactions to information technology influence the actual use of technology, as depicted in Figure 3 (Venkatesh et al., 2003).

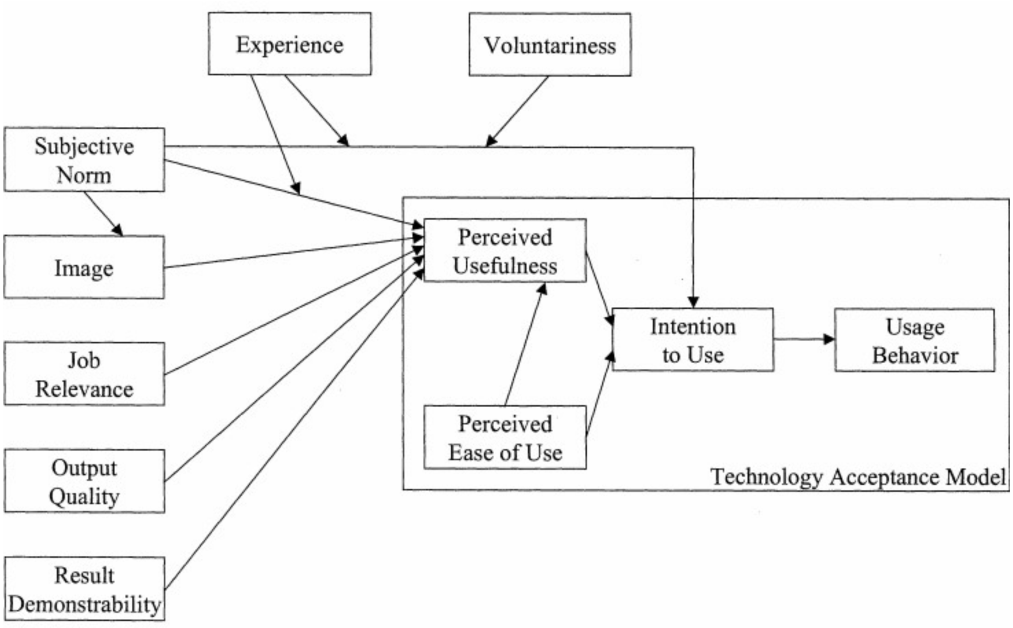
Figure 3: Aspects of technology usage (Venkatesh et al., 2003)



Within educational sciences, the model describes the influencing factors on the likelihood of using digital tools for teaching. Two key factors are at the core of the model: Perceived Usefulness (PU), indicating the extent to which an individual assesses the positive impact of technology on their teaching; and Perceived Ease of Use (PEU), describing one's perception of how effortlessly the technology can be employed. The direct impact of these two factors on Behavioral Intention (BI) are considered, which signifies the intention to use technology for one's teaching (Venkatesh & Davis, 2000).

The extended model (see Figure 4) also incorporates external variables beyond these central factors, such as social influence factors and individual differences. As a first step, we focused on the core concept of the TAM. By examining these central factors, we hoped to gain a more comprehensive understanding of how a single teaching project influences students' intention to independently use AR in their teaching practices.

Figure 4: TAM 2: Extension of the Technology Acceptance Model (Venkatesh & Davis, 2000)



In sum, the TAM appears to be a suitable model for investigating the use of digital technologies (e.g., AR). This article seeks to uncover whether the basic model is suitable and helpful for understanding students' technology acceptance when working with AR. In the following section, we describe a seminar concept and empirically examine the use of digital technologies within it using the TAM.

3 A Concept for the Implementation of AR in Teacher Education

The seminar concept, which aims to teach prospective teachers how to use AR for teaching and learning purposes, is described in the following subsections.

3.1 The AR Application

The AR application used in this article was developed and maintained by the Center for Information and Media Services (ZIM) at the University of Duisburg-Essen, Germany. Originally designed for teaching within the university, the AR application was created to represent the 3D structure of algae in the field of biology (see Figure 5). The application operates based on Unity and can be installed as a single installation file on digital devices. Using the device's camera, predefined QR codes can be scanned, displaying 3D objects through the application. After scanning the code, it is possible to examine, rotate, and move the object in detail. Additionally, supplementary information can be accessed: Further 3D objects, images, informational texts, and videos can be retrieved on an additional level, thereby enriching the 3D object.

The application is individually filled based on the topic, and the associated content is locally stored, allowing for offline use after installation. However, this makes usage outside the directly intended context challenging, as incorporating all available instances would inflate the file size beyond reasonable limits. The option for installation on personal devices enables usage on both university-prepared and personal devices, following a bring-your-own-device approach (Zick & Wefelnberg, 2022).

Figure 5: 3D structure of algae in the field of biology

3.2 Teaching Concept for Integration into the Seminar Context

The teaching concept aims for an experiential-based fostering of digitalization-related competencies, grounded in project- and experience-based learning (Martinez, 2022). As both acceptance and experience are significant predictors of technology use (Mailizar et al., 2021), students' active interaction with application and the underlying processes was encouraged. Regarding this approach, students were asked to independently explore the use of digital media and subsequently reflect on their experiences within a group setting. Our goal was to tackle workplace-related tasks from a student-related perspective, discuss potential solutions, and critically and reflexively assess the results.

The structured process consisted of predetermined steps:

1) Initially, students engaged with the theoretical foundations of learning with digital media in general and models related to professionalization in the field of digitalization competencies in teaching. This included such basics as the Cognitive Load Theory (Sweller, 1994) or the Cognitive Theory of Multimedia Learning (Mayer, 2014), but also specific models, including the Cognitive Affective Model of Immersive Learning for immersive VR (Makransky & Petersen, 2021).

2) Building upon this, the focus shifted to the theoretical foundations of using AR in education. Students received an introduction to the topic of AR and its pedagogically-meaningful uses.

3) Once the theoretical foundation had been established, the practical application phase began with an introduction of the AR application. The functions and features were discussed, followed by a trial phase where students could interact with the application using existing best-practice examples, thus gaining a practical understanding of its functions and processes.

4) Following the individual exploration and trial phase, the teaching concept entered the group work phase where students were asked to design their own (fictional) learning environments. They were instructed to select scenarios where the 3D representation in the AR application would be an appropriate form of representation compared to other less elaborate forms (e.g., printed materials) (Kerres et al., 2021). To guide them through this design process, students received a step-by-step guide outlining important factors for planning media usage and highlighting the relevant conditions for the fictional classroom setting. Consequently, students planned an instructional design along an educational issue. They considered the characteristics of the target group, set educational objectives, and planned the temporal, spatial, and social organization (Kerres, 2018). Further to conceptualizing the use of the AR application, groups also compiled its content, including at least one main 3D object, brief informational texts, accompanying images designed to provide meaningful information, and explanatory videos.

5) These contents were then transferred to the ZIM, who were responsible for the integration into the app. This approach minimized the technical knowledge requirements for the students, allowing them to focus on the app's instructional design and use. Learning Unity and creating entirely unique environments are beyond the curriculum's scope within educational sciences and do not align with the reality of future teaching roles, where existing resources must be thoughtfully incorporated.

6) Once integrated into the app, the groups were provided with installation files. Each group then presented their work to the other seminar groups. The results were tested by other groups and, subsequently, the alignment between the plan and the actual outcome was discussed. This allowed the students to take on the role of future learners, critically and constructively discussing their own work to derive insights for improvement.

7) In the final step, experiences, ideas, and approaches were reconnected to the originally-discussed theory, establishing a comparison between the teaching–learning theory and their own teaching practice.

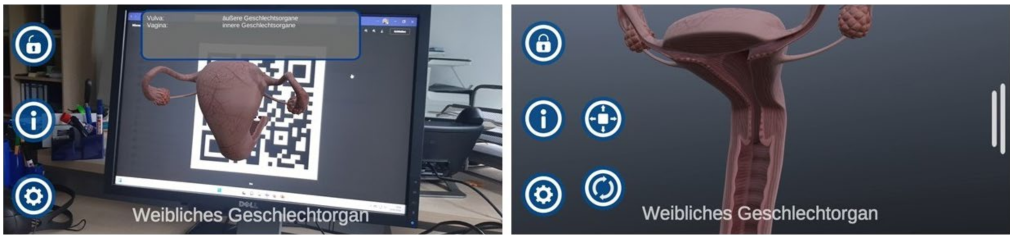
3.3 Seminar Objectives

The seminar aimed to acquaint students with digital media, providing them with the opportunity to independently create and experiment with concepts in a hands-on manner. This approach fostered a reflective method for integrating digital media into their teaching practices. As a first step to gaining insights into the chances and challenges connected to the described seminar concept in general, we collected feedback and experiences throughout the course of the seminar. These insights highlighted different viewpoints to be considered when implementing such a concept in higher education. Simultaneously, the seminar sought to motivate students to incorporate more sophisticated digital media in their own future teaching scenarios.

3.4 Description of an Exemplary Group Work

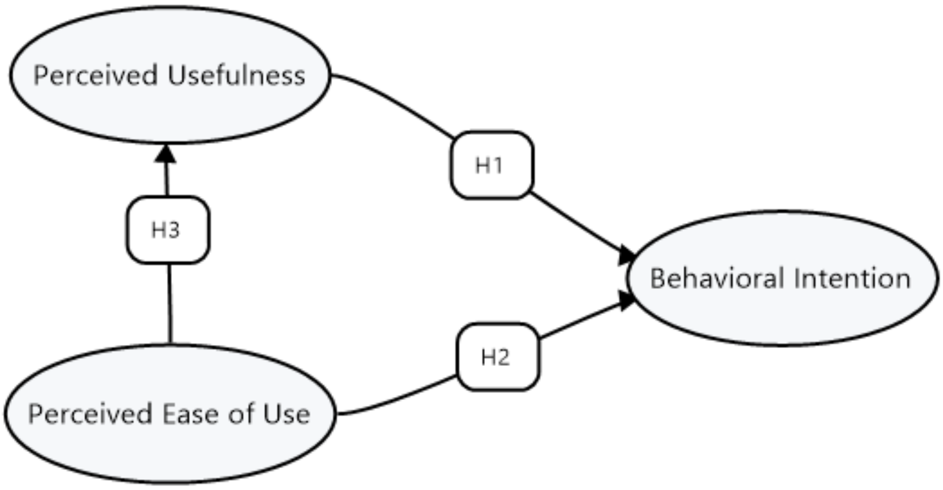
A group of four master's students at the University of Duisburg-Essen developed the following fictional teaching concept in the winter semester of 2022/2023: Sexual education classes in German secondary schools are often conducted using printed materials. The anatomy of female and male reproductive organs is typically explained through illustrations in textbooks. However, secondary school students often struggle to visualize the 3D structures, particularly those within the female body. A 3D representation of the female reproductive organs addresses this educational issue by spatially illustrating structures hidden within the body. A 3D model of the female uterus (allowing for rotation, flipping, and zooming) helps students recognize individual components. Additionally, the 3D model is supplemented with embedded image and text elements (see Figure 6). Cognitive learning objectives (e.g., students distinguishing between inner and outer labia) and affective learning objectives (e.g., students recognizing and appreciating the diversity of vulvas in their external appearance) can be addressed. During a class session, secondary school students can independently or in small groups explore the application on their own mobile devices, using various degrees of freedom (e.g., sequence, duration). The teacher can guide the exploration of the application through suitable instructional methods (e.g., quizzes, media-critical reflection).

Figure 6: Insights into the group work on the 3D model of female reproductive organs for sex education in secondary schools.
3D model: Female Reproductive Organs-X, Section by CVallance @cvallance01 (sketchfab.com). CC BY 4.0 Deed.



Having sufficiently described the seminar concept, we now turn to its accompanying empirical research. Our aim was to examine the factors postulated in the TAM. The TAM is instrumental in this context, considering the subjective perception of the AR's usefulness and the perceived complexity of its application, both influencing BI. As our focus was on the TAM's core elements, we queried only the three concepts of PU, PEU, and BI. Hence, we formulated the following hypotheses (H) so as to better understand the underlying relationships in the use of AR within the seminar context (see Figure 7).

Figure 7: Hypotheses based on the TAM model



H1: PU is a significant predictor that positively predicts BI toward the use of AR for one's own teaching.

H2: PEU is a significant predictor that positively predicts BI toward the use of AR for one's own teaching.

H3: PEU is a significant predictor that positively affects the PU regarding the use of AR in teaching contexts.

4 Methods

This section provides a detailed account of the steps involved in our research approach.

4.1 Framework and Conditions

The seminar was situated within the educational science component of the Master of Education program of the University of Duisburg-Essen. As part of an elective module, students delve into the theoretical foundations of teaching and learning with digital media. Building upon this knowledge, students design media interventions, considering the abilities, life contexts, and prerequisites of the learners. The emphasis lies on pedagogically-justified media selection, media didactic design, and reflection on media usage.

Over the course of two semester hours per week, students, coming from various disciplinary backgrounds, engage in an ungraded study performance, crafting their own digital learning unit. The course accommodates a maximum of 40 participants.

4.2 Seminar Outline

The seminar adheres to the predefined structure outlined in Section 3.2: Students work through the theoretical foundations and necessary understanding for the pedagogically-meaningful use of digital media in teaching. Following this, the focus shifts to AR, with an introductory session providing a comprehensive overview of its applications. From a general understanding of AR, the transition is made to the specific AR application, and the assignment is introduced.

Guided by instructional guides, students form groups and develop a concept for a lesson incorporating the AR application. Emphasis is placed on the pedagogically-meaningful integration of AR. Alongside the concept, students compile the content, including the 3D object and additional informational materials. The ZIM externally incorporates these contents into the application. The installation instance created is then returned to the students for installation, with additional devices provided to preempt technical issues.

In a concluding session, students briefly present their content, explaining how AR was employed. Following this, students test the results of other groups. The seminar concludes with a discussion of solutions, reflecting on both the intended and achieved effects.

4.3 Data Collection

Two datasets were collected. The first was a structured quantitative assessment administered at the end of the semester after completion of the described seminar. These data were used to answer the main research questions. To test the proposed hypotheses and assess the various factors of the TAM (Venkatesh & Davis, 2000), a questionnaire (the items of which are included in the appendix) was administered using an online survey tool (Limesurvey) following the group discussions. The two-part questionnaire initially gathered anonymous data on gender and experience with AR in an educational context. Subsequently, individual feedback regarding the variables PU, PEU, and BI was collected.

The items were based on the questionnaire by Sprenger and Schwaninger (2021), which was translated into German by a bilingual psychologist, focusing on the use of digital media in an educational context. This process resulted in 5 items per variable. Responses were collected on a 7-point Likert scale, where 1 indicated "completely agree" and 7 "completely disagree," following the usual TAM questionnaire format.

The second dataset was a summary of the collected feedback and experiences made throughout the seminar. This included comments made by students during the work phases, observed situations, and student interactions between themselves and technology. These more unstructured observations described the seminar's background, as well as its possible opportunities and challenges.

5 Results

This section describes the sample, descriptive statistics, model analysis, and general findings.

5.1 Description of the Sample

Data were collected from 23 students. All participants were either enrolled in the master's program in educational sciences or had – at the beginning of the seminar at least – registered their bachelor's thesis, which had to be completed within three months. Students pursued two subject areas and attended additional seminars and courses related to the general theme of educational sciences. This resulted in a mix of various combinations of subject areas and specific seminars that students attended. Moreover, the seminar was limited to secondary schools.

The questionnaire analysis revealed that 19 of the participants were female, with the remaining 4 being male. Regarding prior engagement with AR in teaching, 3 participants answered affirmatively, while 20 responded negatively. One person had to be excluded from further analysis due to an incomplete questionnaire, and two were removed based on statistical outlier checks. Accordingly, we were left with a final sample of 20 participants.

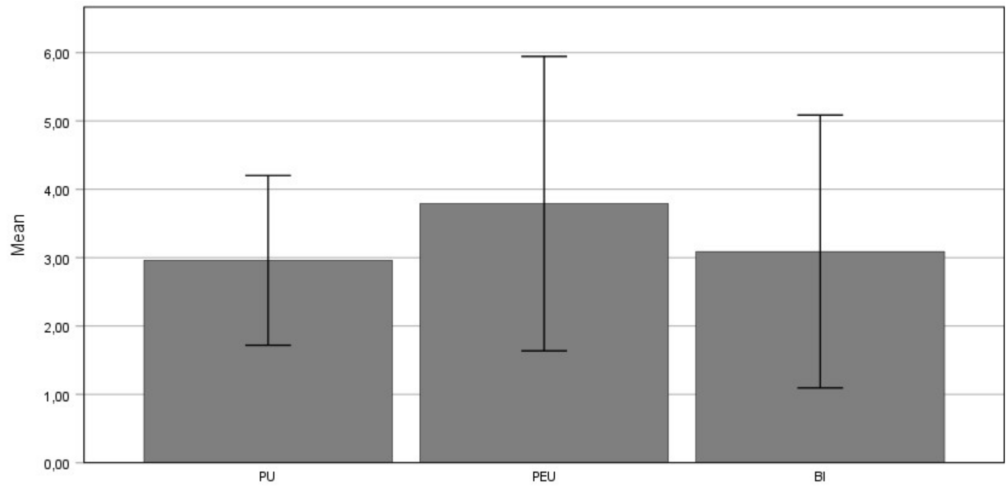
5.2 Descriptive Statistics

Concerning the fit of items for the variables, the following Cronbach's alphas were obtained: PU: 0.74, PEU: 0.89, and BI: 0.92.

An initial examination of the results for each factor revealed a mean value of $M = 2.96$ for PU, indicating a tendency toward agreement. Similar results were observed for BI with $M = 3.09$. However, PEU was assessed less positively, with a mean value of $M = 3.79$. Compared to other studies focusing on the acceptance of digital media in education, these values were close to the expected range, with PEU being slightly weaker than anticipated (Sprenger & Schwaninger, 2021).

One notable observation was the significant dispersion of values, particularly for PEU and BI (shown in Figure 8). Without a multiplier, the standard deviation for these factors were 1.00 (BI) and 1.08 (PEU).

Figure 8: Means of the TAM factors. The standard deviation is visualized using error bars (+/- 2 SD)



Error Bar: +/- 2 SD

These deviations may indicate either a general heterogeneity in assessments across the entire group or variations within subgroups among the students.

5.3 Model Analysis

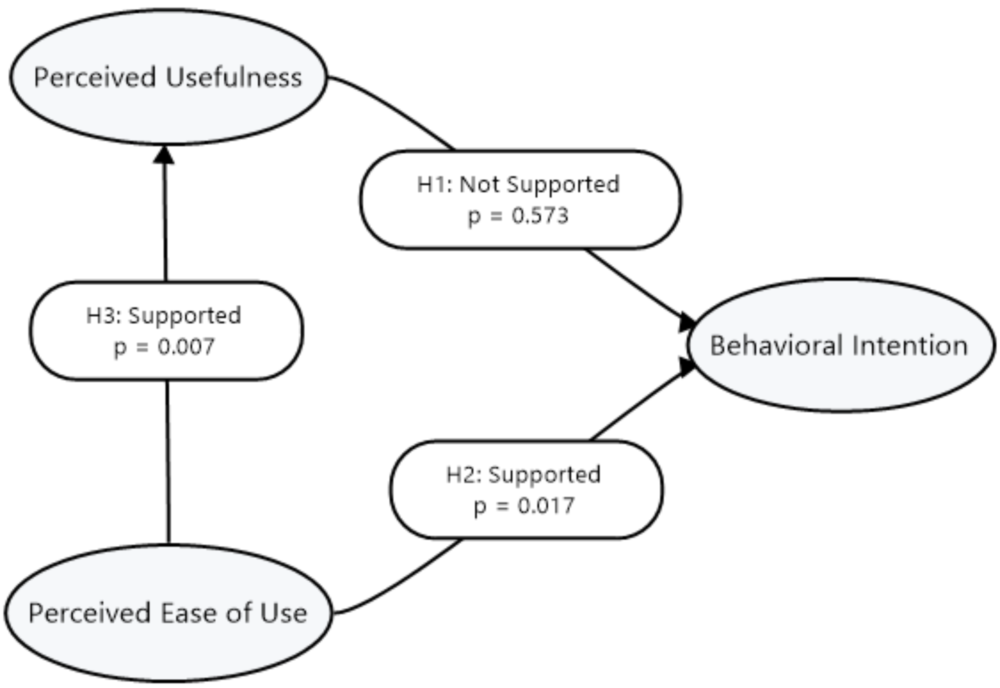
Beyond the mere depiction of the current state, the fit of the TAM model in general and the support for the hypotheses (see Section 3.4) were analyzed. For this purpose, two Analyses of Variance (ANOVAs) were conducted, setting the alpha at 0.05.

Firstly, BI was set as the dependent variable for the independent variables PU and PEU (H1 and H2). In this case, an R^2 of 0.45 (adjusted $R^2 = 0.39$) indicated a high goodness of fit (Cohen, 2013). In the overall consideration of the model's significance, the predictors PU and PEU statistically significantly predicted the criterion BI, with $F(2.17) = 6.96$, $p = 0.01$. The power analysis of the model additionally revealed that, with a power of 0.9 and the determinant coefficient R^2, the sample of 20 students was of a sufficient size (i.e., above the threshold of 19). Examining the regression coefficients, PEU had a significant positive impact on BI, with a regression coefficient of 0.55 and $p = 0.02$, whereas PU had a non-significant positive impact, with 0.21 and $p = 0.57$.

Beyond these two paths, the TAM model also described a relationship between PEU and PU, with the former influencing the latter (H3). This path was analyzed with an additional ANOVA. Here again, a high goodness of fit was observed according to Cohen (2013) with $R^2 = 0.34$ (adjusted $R^2 = 0.31$). Additionally, PEU significantly predicted PU with $F(1.18) = 9.36$, $p = 0.01$. The regression coefficient at this point is 0.34.

In light of the above, H2 and H3 were supported, whereas H1 was not, as depicted in Figure 9.

Figure 9: Hypotheses testing



5.4 General Findings

During the implementation of the seminar, test runs were conducted in the described and previous semesters to proactively address potential technical and individual challenges. Individual student feedback was collected, alongside our own observations. These insights gained from the seminars are below categorized into “technical” and “individual,” and corresponding solutions are presented where possible.

5.4.1 Technical Insights

Smartphone compatibility: A primary issue was the availability of compatible smartphones with operating systems facilitating seamless app use. The solution involved providing university devices on which the application for the learning group was pre-installed.

Availability of 3D models: The concepts of the students were limited to content for which free 3D models were available and could be easily obtained from the internet. Teaching students how to design or construct their own 3D objects would have likely enhanced their independence in topic selection. However, incorporating this into the seminar would have exceeded its scope, making it challenging for students to create appropriate objects. This led to instances where students had fully developed concepts, but no suitable object was available, resulting in the abandonment of the idea. To avoid investing too much work into a theme that cannot be implemented, students should first search for a suitable 3D object after deciding on an idea and then proceed with the full conception.

AR interface/content integration: The process of integrating content into the AR application came with both advantages and disadvantages. While this approach reduces the effort and prior knowledge required from students in dealing with Unity, it simultaneously results in a strong dependence on the work of an external entity. Minor changes could not be addressed independently and had to undergo a revision loop before implementation. To solve this issue, agreements were made before the start of the semester regarding specific feedback times, and the testing of content by groups was temporally separated from the elaboration so as to incorporate corrections. To address general errors related to the program or content, a guide was created that precisely explains the content and structure. This was designed to provide clarity and support to students navigating potential challenges in the integration process.

5.4.2 Individual Insights

Diverse understanding of digital media: Students exhibited a wide spectrum of knowledge levels and skills in handling digital media. This range encompassed a basic lack of comprehension regarding 3D objects, leading to the submission of image files instead of 3D models. Some students attempted to access information in the application by using general QR code scanners, revealing a misunderstanding of its general functionality. To address this, a guide has been created elucidating the application's function and structure in conjunction with various files.

Various experience with AR: Students gathered distinctly different experiences with AR in their daily lives and teaching practices. While some had previously used AR in subject-specific courses, exploring distinctions and teaching possibilities, a nuanced introduction to the theoretical foundations of learning with AR is necessary to illustrate its meaningful applications.

Differing proficiency in lesson planning with digital media: Beyond varying levels of knowledge regarding digital media and AR, there are differences in familiarity with lesson planning using digital media. Not all students grasped the distinctions between method and medium, structured planning processes, and such critical factors as contextual conditions. Materials were provided for further support, offering precise flowcharts and essential points, following the scaffolding principle.

6 Discussion

This section first discusses our results in general, before reflecting on the developed seminar, identifying limitations, and, finally, summarizing our findings.

6.1 Data Analysis

The data analysis revealed several key points to be considered. Firstly, there were strong variations within TAM factors, indicating the need for adjustments in teaching methods to cater to a heterogeneous group of students. Further research is recommended to explore the reasons behind this heterogeneity, especially in the context of introducing students to media usage. Moreover, we believe it pertinent to highlight the positive attitude toward the usefulness of AR as a basis for future work.

In terms of TAM suitability, the model proved to be generally suitable for investigating student acceptance regarding the use of digital media for their own learning. Regarding H2 and H3, PEU proved to significantly positively predict: (1) BI toward the use of AR for one's own teaching, and (2) PU regarding the use of AR in teaching contexts. The significant impact of PEU is noteworthy, emphasizing the need for a focus on this aspect. Nevertheless, we failed to confirm H2, as we found no significant relationship between PU and BI. Future research directions should further explore the connection between PU and BI to confirm or revise the significance not identified in the small pilot sample.

Furthermore, the need for more detailed research concerning individual perspective is evidenced by the significant role played by teachers' perspectives in technology acceptance (Tzima et al., 2019). More information regarding the additional factors should be included for both the subjective perspective, such as the "social norm" described by Ibili et al. (2019) and expectations regarding technology (Dalim et al., 2017). This could help understand the heterogeneous results.

The analysis also shed light on challenges and opportunities within the evolving landscape of technological possibilities in education. A significant proportion of students lacking prior exposure to AR in an educational context was noted, which did not align with technological advancements or the demand for curricular adaptation. The broad variation, particularly in PEU, and the overall low level of this factor indicate room for improvement. More positively, the data showed that students recognize AR's usefulness in teaching.

In sum, the data underscore existing challenges and opportunities, emphasizing the importance of addressing heterogeneity, refining the TAM model application, and aligning educational practices with the evolving landscape of technological possibilities.

6.2 Reflection of the Concept and Future Directions

The seminar concept highlights the fundamental need for the (further) development of seminars with the goal of integrating the use of more complex digital media into university teaching. Beyond theoretical exploration, emphasis should be placed on developing students' competence in using and handling these media independently. Particularly concerning the preparation of future teachers for independent media use in their own classrooms, it is challenging to justify instances where students have had no contact with these technologies. Preceding acceptance of personal use, prospective teachers should at least acquire the basics of how these media function.

For the seminar's execution, there are new starting points for the current state and future development. Firstly, providing devices that prevent compatibility issues and allow reliable use of the AR application is crucial. This approach can address socio-economic differences and ensure universal access. Assuming that students have had no prior contact with AR, preparatory materials and support services should be available to address questions and basic difficulties. Accordingly, heterogeneity should be considered so as to neither underchallenge students with experience nor leave behind those who need assistance. Higher education didactics should not rely on the assumption that students' media affinity is sufficient for their purposeful and reflective use, both generally and in teaching specifically.

A highly limiting factor that should be considered when asking students to conceptualize their own design is the very restricted availability of freely-usable 3D models, which serves to limit opportunities for creating custom environments.

The seminar concept aims to reduce barriers, especially in the area of PEU, facilitating simpler handling. Additionally, efforts should be made to find more instructors to explore and integrate AR use in subject didactics (e.g., biology). In terms of integrating content into the application, an approach that allows students to easily drag and drop content is required, as this would increase control and minimize the perception of the ZIM as a black box. Furthermore, best-practice examples from students should be collected as open educational resources to provide new learners with insights and possibilities.

6.3 Limitations

Although the concept and acquired data were predominantly based on a pilot seminar, several limitations need to be considered. First of all, the sample size was relatively small, due to the fact that the research was conducted as part of a regular university course. Therefore, there may be issues regarding the application's use by a larger group. Moreover, the results should be interpreted with caution as they may not be readily generalizable due to the small sample size. We intend to implement and empirically investigate the seminar concept with larger groups of students in the future. Furthermore, the backgrounds of our participants were of a heterogeneous nature, both regarding their academic history and their personal background. Depending on the specializations and fields of study, different courses and seminars are visited, thereby influencing knowledge bases. Therefore, future studies should consider and assess prior knowledge and experience of AR learning applications and technologies. Additionally, the personal access to digital media might differ, thereby influencing attitude and knowledge. In order to gain more exhaustive insights into the different influences, more test items would need to be included. Generally speaking, there is a need for a more detailed understanding of the underlying individual factors, as discussed in Section 6.1.

6.4 Conclusion

In sum, this paper presented a hands-on seminar concept that enabled students to plan, design, and test a purposeful AR-based lesson on a subject of their choice. For most of the students, the seminar provided their first opportunity to engage with AR, revealing a significant gap between the imperative to incorporate it into their own curriculum planning and the preparation provided in their future teacher training. Nevertheless, the overall perception of AR's utility in teaching was found to be high, despite the perceived challenges in using the technology for educational purposes. According to the TAM (Venkatesh & Davis, 2000), these variables can be leveraged to enhance the likelihood of AR adoption in the professional lives of future teachers. Further studies incorporating validated German questionnaires and more detailed questionnaire items regarding the additional factors of the TAM model are necessary to validate the specific pathways within the TAM and to explore the reasons for the considerable variance in individual perceptions. In essence, this paper emphasizes the necessity for additional seminar concepts that address the imperative of preparing teachers for the demands of integrating rapidly-evolving digital technologies into their daily teaching practices. These concepts should be accompanied by rigorous scientific evaluation to establish a foundation for the sustainable adaptation of curricula in higher education and teacher training.

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Appendix

Category	German Question	English Translation
Gender	Geben Sie bitte Ihr Geschlecht an.	Please specify your gender.
Experience	Haben Sie sich vor diesem Seminar bereits mit Augmented Reality in der Lehre beschäftigt?	Were you familiar with Augmented Reality in education before this seminar?
PU	Der Einsatz von Augmented Reality führt zu einer Verbesserung des Unterrichts.	The use of Augmented Reality enhances the quality of teaching.
PU	Augmented Reality erleichtern das Lernen der Unterrichtsinhalte.	Augmented Reality facilitates the learning of course content.
PU	Augmented Reality erleichtern das Verstehen der Unterrichtsinhalte.	Augmented Reality facilitates the understanding of course content.
PU	Mit dem Einsatz von Augmented Reality würden Schüler*innen die Unterrichtsinhalte schneller lernen.	With the use of Augmented Reality, students can learn course content faster.
PU	Ich finde Augmented Reality nützlich für meine Lehre.	I find Augmented Reality useful for my teaching.
PEU	Die Bedienung von Augmented Reality zu erlernen, ist einfach für mich.	Learning to operate Augmented Reality is easy for me.
PEU	Augmented Reality ist einfach zu benutzen.	Augmented Reality is easy to use.
PEU	Mit Augmented Reality zu interagieren, fände ich einfach.	Interacting with Augmented Reality would be easy for me.
PEU	Insgesamt denke ich, dass es einfach ist, Augmented Reality zu benutzen.	All in all, I think it is easy to use Augmented Reality.
PEU	Mit Augmented Reality zu interagieren ist klar und verständlich.	Interacting with Augmented Reality is clear and understandable.
BI	Wenn es verfügbar ist, plane ich, Augmented Reality häufig für meine Lehre einzusetzen.	Assuming I had access to Augmented Reality, I would use it often for my teaching.

BI	Wenn Augmented Reality verfügbar ist, beabsichtige ich, es während des Schuljahres häufig zu benutzen.	Assuming I had access to Augmented Reality, I would use it often during the school year.
BI	Wenn Augmented Reality verfügbar ist, werde ich es versuchen häufig einzusetzen.	Assuming I had access to Augmented Reality, I would try to use it often.
BI	Angenommen ich hätte Zugang zu Augmented Reality, würde ich sie benutzen.	Assuming I had access to Augmented Reality, I would use it.
BI	Wenn ich Zugang zu Augmented Reality hätte, gehe ich davon aus, dass ich es benutzen würde.	If I had access to Augmented Reality, I predict that I would use it.

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