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Augmented Reality in the Science Classroom—Implementing Pre-Service Teacher Training in the Competency Area of Simulation and Modeling According to the DiKoLAN Framework

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Abstract: The digitalization of everyday school life has gained increasing importance for teachers in recent years. In Germany, this is especially true since the publication of the strategy on "Education in the Digital World" by the Standing Conference of the Ministers of Education and Cultural Affairs of the Länder in 2016, which calls for the acquisition of digital competencies by students. In this regard, it is of great importance that future teachers acquire important skills in the field of digitalization during their teacher training in order to effectively and pedagogically use digital media in instruction. In this paper, we present the concept of an intervention on the topic of "Simulation and Modeling" from the competency framework DiKoLAN, which provides possible guidance in relation to the question "which competencies in the field of digitalization should be taught during teacher training?" One focus of the presented concept is the technology of "Augmented Reality," which has already been described as an effective teaching and learning tool. Furthermore, evaluation results of the seminar are presented, which examine both the effectiveness in terms of conveying the desired competencies through the measurement of self-efficacy expectations, and the attitudes of the pre-service teachers towards the use of AR in science education. The evaluation of the intervention measure shows a significant increase in pre-service teachers' self-efficacy expectations across all areas of competencies to be taught, as well as a significantly more positive attitude towards the use of AR in science teaching.

Keywords: AR; DiKoLAN; TPACK; science education; student teachers; simulation; modeling; self-efficacy expectations; DPACK; digitally related pedagogical and content knowledge

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1. Introduction

Augmented Reality (AR) is a technology that creates a connection between the real environment and virtual information. It supplements "reality" with additional digital content, such as videos, texts, images, etc., through digital output devices such as mobile phones, tablets, or AR/VR headsets (Head-Mounted Displays, such as the visionPro from Apple or HoloLens2 from Microsoft). This interaction occurs in real time, utilizing 3D registration that assigns fixed positions to digital content in the real three-dimensional world [1].

AR applications are a promising modern approach to facilitate learning [1,2]. AR apps have been shown to be effective for learning [3–14], especially for visualizing and understanding abstract and difficult-to-access science concepts and phenomena in three-dimensional representations [4,6,12,15–26] and superimposing auxiliary information [14,27–30]. Furthermore, positive effects of using AR apps on motivation and interest [7,14,31–34], attention and self-regulation [34–36], attitudes towards science education [4,37], laboratory skills [37–39], and academic achievements [4] have been shown, and augmented reality could be successfully used to promote explorative [18] and collaborative [40] learning.

AR is also considered significant in the industrial sector, where it is ranked among the top 10 technology trends [41]. The particular importance of implementing AR in chemistry education from a discipline-specific perspective was demonstrated recently when the International Union of Pure and Applied Chemistry (IUPAC) declared the virtual reality continuum to be one of the "Top Ten Emerging Technologies in Chemistry 2022" [42]. AR thus represents an important technology, especially in the field of the natural sciences.

However, the limited adoption of AR in classrooms may be attributed to the fact that, until recently, AR applications could only be developed by professionals with programming skills, and the necessary digital devices were not readily available in schools. However, there is now software available that allows for the creation of AR applications without the need for programming skills, making AR not only theoretically but also practically a feasible tool for teachers [1].

Another challenge is the high level of skepticism among pre-service teachers regarding digital media in general [43] and regarding AR in particular, which necessitates not only imparting theoretical content to them, but also embedding these contents in practical examples that can be used in school practice and have a demonstrable positive effect on student learning [43]. This also applies to the technology of AR.

Therefore, applications of the future technology AR in professional life as well as learning supportive applications in science teaching should absolutely and urgently be integrated into science pre-service teacher training. To ensure the future use of this technology in regular school operations, it is necessary to introduce pre-service teachers to this field, to train them in its applications, and to help them building necessary digital competencies. This can help reducing barriers related to the creation and use of AR, and even enable prospective teachers to serve as multipliers in schools in their future profession. According to Jang et al., "positive attitudes toward AR and VR-enabled instruction have an effect on their continuous use in the classroom" [44] (p. 6806), thus, "promoting teachers' attitudes toward technology use would have a positive impact on the more use of AR and VR in classrooms" [44] (p. 6806).

However, since there is no teaching budget available for new supplementary seminars, and hence, these topics must be integrated into existing curricula, a way must be found to integrate these topics into existing courses. This raises the question of how, despite limited time and personnel resources, prospective science teachers can firstly build up basic competencies in the overarching competency area of simulation and modeling, and secondly how the attitudes of prospective teachers towards the use of AR in science teaching can be positively influenced in such a way that, after participating in such a seminar, student teachers are sufficiently interested and motivated to continuously use AR-enabled instruction in the classroom [44] and to continue their own education in AR-related topics in the sense of life-long learning.

This leads to the following research questions:

RQ 1. *Can a 2 × 90 min intervention concerning pre-service teachers' digital competencies in the area of Simulation and Modeling significantly affect pre-service teachers' respective self-efficacy expectations?*

Based on the work of Henne et al. [45], which demonstrates that targeted promotion of digital competences through specifically designed teaching and learning scenarios can lead to significant increases in the self-efficacy expectations of pre-service teachers, we assume that similar intervention measures with doubled time on task could result in even greater effects in all addressed competence areas. This leads us to the following hypothesis:

Hypothesis 1. *The developed intervention concerning pre-service teachers' digital competencies in the area of Simulation and Modeling has a strong positive effect on pre-service teachers' respective self-efficacy expectations.*

RQ 2. *Can a 90 min intervention significantly influence pre-service teachers' attitudes towards the use of AR in science education?*

Through various studies, for example, Vogelsang et al. [46], it has been found that university teaching and learning activities can not only enhance pre-service teachers' self-efficacy expectations in the area of digital competences but also positively improve their attitude towards the use of digital media. Since the aforementioned studies by Henne and Müller [45] were only able to selectively promote individual competence areas, we also assume selective promotion in the domain of attitudes towards AR in science education. This leads us to the following hypothesis:

Hypothesis 2. *The developed intervention has a strong positive effect on pre-service teachers' attitudes towards the use of AR in STEM education.*

In this paper, we present the design and evaluation of two specific seminar sessions (90 min each) focused on the field of simulation and modeling, which extensively addresses the technology of AR. The goal of these sessions is twofold: to impart the competency expectations from the area of Simulation and Modeling within the DiKoLAN framework, and to improve the attitudes of pre-service teachers towards the use of AR in science education. To evaluate the seminar, we conducted two sub-studies, using questionnaires to examine the self-efficacy expectations of prospective teachers related to their competencies in the area of simulation and modeling, as well as changes in their attitudes towards the use of AR in science education.

2. Theoretical Frameworks

2.1. DiKoLAN—Digital Competencies for Teaching in Science Education

As both the study design and the course design are based on the same theoretical framework, here we briefly describe the DiKoLAN (Digital Competencies for Teaching in Science Education) framework [47]. For an in-depth discussion, see [48,49]. The DiKoLAN framework is based on the initiative to promote digitization in schools, the European Framework for the Digital Competence of Educators (DigCompEdu) Redecker [50], the TPACK framework [51], and the DPACK model [52]. It serves as a guideline for educators training pre-service teachers in science education and includes an organizational framework that encompasses seven core areas of digital competence specific to teaching in science education (physics, chemistry, and biology). These seven areas can be divided into four more general areas (*Documentation*, *Presentation*, *Communication/Collaboration*, and *Information Search and Evaluation*), and three more subject-specific areas (*Data Acquisition*, *Data Processing*, and *Simulation and Modeling*) (Figure 1). These competency areas are framed by *Technical Core Competencies* and are embedded in the *Legal Framework*. Within the seven core competency areas, subordinate operationalizable competency expectations can be found, which are structured according to the TPACK and DPACK model and the competency levels (*Name*, *Describe*, and *Use/Apply*). Figure 2 shows an overview of the individual competencies of the Simulation and Modeling domain. This clear structure provides an ideal starting point for defining learning objectives, planning teaching–learning scenarios and developing questionnaire items. Figure 3 illustrates the breakdown of the nomenclature of competencies found in the DiKoLAN framework.

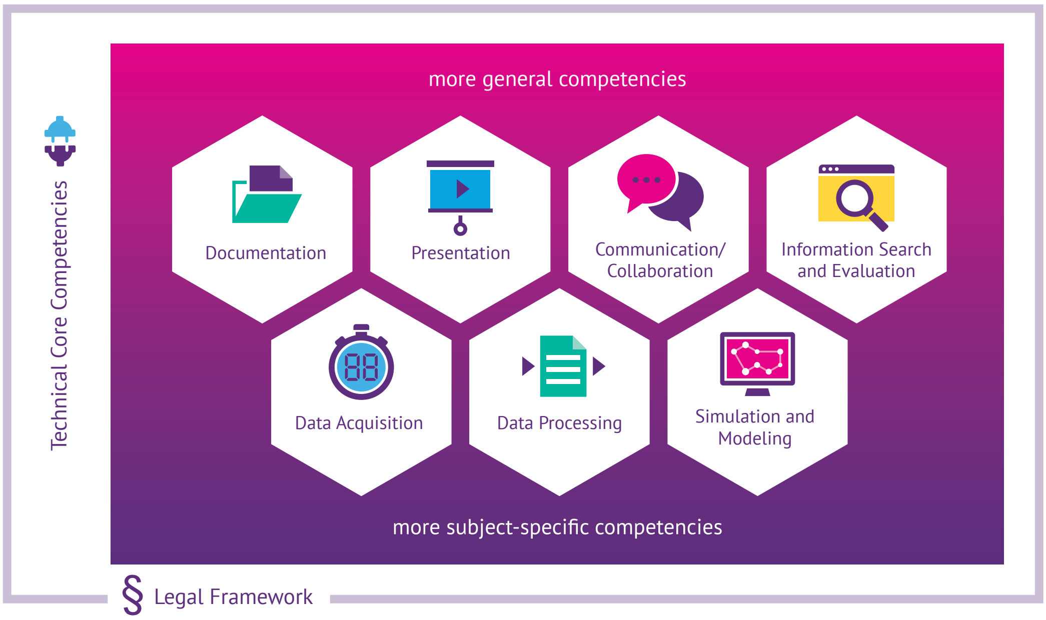

Figure 1. Graphical representation of the DiKoLAN competency framework (https://dikolan.de/en (accessed on 10 July 2023)) [47,48].

	Teaching (TPACK)	Methods, Digitality (TPK)	Content-specific context (TCK)	Special tools (TK)

Name	**SIM.T.N1** Name scenarios for appropriate use of digital simulations and modeling (e.g., spreadsheet, Geogebra for use in teaching) as well as software and strategies for use in a specific teaching-learning scenario, e.g.,
	◆ As a way of gaining knowledge
	  ◇ For lack of other affordable, accessible and safe methods
	  ◇ As a subject-specific working method
	◆ As a temporally optimized form of data acquisition
	◆ As an interactive method
	◆ As an approach for a targeted, variable model criticism
		SIM.M.N1 Name advantages, disadvantages, typical features and limitations in teaching-learning scenarios considering, e.g.,
		◆ Technical correctness (simplification)
		◆ Model variants, normative (recipes, calculation of interest), descriptive (weather report, catenary)
		◆ Quality of representation
		◆ Time required (calculation time)
		◆ Instruction time
		◆ Realization of risk-free, fault-tolerant spaces (security aspects)
		◆ Properties of the respective mathematical models (e.g., parameters, rounding errors, input accuracy)
		◆ Necessary prior knowledge
		
		SIM.M.N2 Name advantages and disadvantages compared to analog simulations (business games).
			SIM.C.N1 Name several science scenarios in which simulation or modeling is used to gain knowledge (e.g., temperature fields, magnetic fields, climate models).
			
			SIM.C.N2 Name at least two methods of digital simulation or modeling in research scenarios (e.g., Lotka-Volterra population dynamics).
			
			SIM.C.N3 Name several data sources from which data applicable to modeling can be drawn/referenced (e.g., weather data, populations, measurements from professional sciences).
			
			SIM.C.N4 Name insights gained from simulations (e.g., material stress, crash testing, weather forecasting, global warming).
			
			SIM.C.N5 Name different target categories of the use of simulations:
			◆ Prognostic → generation of values
			◆ Analytical → comparison with measured values
			◆ Illustration → mediation
			◆ Integrated → in a self-learning process gaining of knowledge
			
			SIM.C.N6 Name different target categories of the use of modeling applications
			◆ Prognostic → generation of measured values
			◆ Analytical → comparison with measured values
				SIM.S.N1 Name several programs or web packages that can be used to perform simulations and modeling (away from a spreadsheet such as Excel).
				
				SIM.S.N2 Name data fundamentals, skills, and necessary prior knowledge of the operator/user required for digital modeling, such as:
				◆ Programming and syntax
				◆ Hardware required (performance)
				◆ Data pool size for calculations
				
				SIM.S.N3 Name several simulations and approaches to simulations:
				◆ To generate data in the cognition process, for example, with a spreadsheet program
				◆ For comparison with experimentally obtained data, for example, with a spreadsheet program
				◆ To illustrate technical correlations, for example, with PhET simulations
				
				SIM.S.N4 Name characteristics of a simulation:
				◆ The transfer of a context of meaning from one object representation to another
				◆ Structural representation
				◆ Procedural representation
				◆ Reduction of complexity

Describe (including necessary procedures)	**SIM.T.D1** Describe didactic prerequisites for the use of simulations and modeling in the classroom and their effects on the respective teaching methods as well as access to basic competencies made possible by digital systems (especially in the competency area of knowledge acquisition and, if applicable, communication).	**SIM.M.D1** Describe and evaluate simulations and modeling software in terms of motivation (usability, attractiveness, clarity of description and objectives), content (relevance, scope, correctness) and methodology (flexibility, matching to target group, realization, documentation). **SIM.M.D2** Describe advantages and disadvantages compared to analog simulations (business games).	**SIM.C.D1** Describe the gain of knowledge with simulations and their advantages/disadvantages as well as their epistemological limitations in different concrete research scenarios.	**SIM.S.D1** Edit the functional scope of the named packages or programs with regard to: ◆ Parameterization ◆ Computing time ◆ Mathematization and GUI or model description ◆ Output options (as graphs or data sets)
Use/Apply (practical and functional realisation)	**SIM.T.A1** Planning and implementation of complete teaching scenarios with the integration of simulations or modeling and the consideration of appropriate social and organizational forms.			**SIM.S.A1** Perform at least one modeling exercise including simulation and results validation.

Figure 2. Competency expectations in the core competence area *Simulation and Modeling*, defined in the DiKoLAN competence framework [47,48].

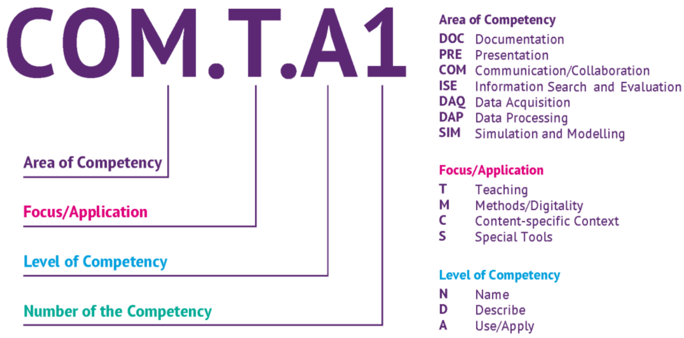

Figure 3. Graphical representation and breakdown of the nomenclature of competency expectations in the DiKoLAN framework [47]. Adapted with permission from [45]. © 2020 Joachim Herz Stiftung.

2.2. Theory of Planned Behavior

In order to achieve the goal of motivating pre-service teachers to use AR in their own teaching in the future, it is not enough to simply provide the necessary skills and information and thereby encourage the pre-service teachers' self-efficacy expectations. Pre-service teachers must also develop the intention to actually use this technology. An indication of the accuracy of this statement exists in the Theory of Planned Behavior (TPB), which is a psychological model developed by Icek Ajzen that aims to predict and describe human behavior [53]. TPB assumes that a person's intentions significantly influence his or her behavior. It further assumes that these intentions are influenced by three factors: attitude (personal evaluation of the behavior and perception of the resulting consequences), subjective norms (perceived social expectations to perform a certain behavior), and perceived behavioral control (belief of having the necessary resources and skills to perform a certain behavior). Ultimately, the interaction of these three factors influences a person's intention to perform a particular behavior [54]. Based on this model, it can be said that it is not only important for prospective teachers to acquire the necessary skills, but also to foster the intention to use AR. Only in this way can the goal be achieved that the desired behavior emerges from competencies, information, and finally the proper intention, so that pre-service teachers will use AR in the future and, ideally, also continue their development in this area.

3. Methods and Materials

3.1. Sample

A total of $N = 31$ pre-service teachers for science subjects at secondary schools (German Gymnasium, specifically) who participated in a seminar specifically designed to promote digital core competencies for teaching in science education according to the DiKoLAN framework were invited to take part in the study. More than 90% of the pre-service teachers took part in the voluntary pre- and post-test surveys ($n = 29$; 18 female, 11 male; $M = 23,9$ years old, $SD = 1.94$; 18 biology, 15 chemistry, 7 physics, multiple subjects possible; $n = 12$ in winter semester 2021/22, $n = 11$ in summer semester 2022, $n = 6$ in winter semester 2022/23). However, only five participants completed all single surveys. Hence, in the statistical analyses, the single statistical tests are administered with pairwise deletion of incomplete data and data imputation has been omitted. Actual sample sizes are given for each test.

3.2. Instruments

Two questionnaires are used to test the hypotheses: a questionnaire on self-efficacy expectations regarding the digital competencies in the area of simulation and modeling defined in the DiKoLAN framework, and a questionnaire to assess attitudes towards AR in science education derived from a well-established questionnaire on attitudes towards general use of digital technologies in science teaching based on the theory of planned behavior.

3.2.1. Questionnaire on Self-Efficacy Expectations Regarding Digital Competencies for Teaching in Science Education in the Competency Area of Simulation and Modeling

To assess the effectiveness of the designed teaching and learning module, changes in participants' self-efficacy expectations were measured using an online questionnaire developed by the Digital Core Competencies working group and based on the DiKoLAN framework [47,48], which has already been used in several studies [45]. The items used in the questionnaire are aligned with the DiKoLAN competency framework and its associated competency expectations (Figure 2). They are measured using an eight-point scale reflecting participants' agreement with statements regarding their skills "I can . . . " from "1— Can't do it at all" to "8—Can do it fully". For the purpose of evaluation, the items in the questionnaire can be directly assigned to individual competency expectations within the competency framework, with the naming of the items in the survey following the nomenclature of the DiKoLAN competency framework (Figure 3) [45]. Since in the first sub-study all competency expectations mentioned in the competency area "Simulation and Modeling" of the DiKoLAN framework were addressed, all corresponding test items in the pre-test and post-test are combined to one 24-item scale "Simulation and Modeling" covering all technology-related facets of the TPACK framework.

3.2.2. Questionnaire for Assessing Attitudes towards AR in Science Education

The questionnaire used in the second study was developed by Fellows of the *Kolleg Didaktik:digital* of the *Joachim Herz Foundation* and originally used to evaluate courses developed in the Kolleg Didaktik:digital to promote the use of digital media in science education, and to gain insights into the use of digital media specifically in science-related pre-service teacher training [46]. This questionnaire is based on the Theory of Planned Behavior (TPB). The investigation of all items is based on four-point Likert scales, with only the endpoints labeled ("1 = do not agree at all", and "4 = agree completely"). The constructs being examined are:

- Attitudes towards learning with AR in the classroom (ATT);
- Motivational orientation to the use of AR in the classroom (MOT);
- Subjective norm expectations for the use of AR (SUB);
- Self-efficacy expectations on the use of AR (SEE);
- Perceived constraints to the use of AR (CON).

For the present study, 36 items from the original questionnaire were reformulated and administered to master's students (i.e., pre-service teachers) in natural science disciplines in 3 consecutive semesters within a subject didactics seminar (Table A1 in the Appendix A lists the items).

We are aware that there were instruments available designed for the study of attitudes towards AR (e.g., the Attitudes toward AR applications, ARAAS scale) [55], but we required an instrument designed for the field of science education. Therefore, we adapted the measurement instrument of Vogelsang et al. [46] to our needs.

3.3. Study Design

Two sub-studies were conducted to answer the research questions. The first study, to survey Self-Efficacy Expectations, used a pre–post follow-up design, for which data were collected one week before the first intervention, shortly after the first intervention, and one week after the second intervention. The second data collection period thus represents both the post-test of the first intervention session and the pre-test of the second session, resulting in three measurement periods for this study. An online questionnaire was used to collect data, for which pre-service teachers were given access to LimeSurvey [56] via email.

The second sub-study dealt with attitudes towards AR in science education. For this purpose, a handwritten questionnaire was used, which was completed directly before and after the second intervention, which dealt with the topic of simulation and AR. This resulted in two measurement periods for the second sub-study.

The data for the first sub-study were collected from winter semester 21/22 to winter semester 22/23, while the data for the second sub-study were collected in summer semester 22 and winter semester 22/23. Figure 4 presents a graphical representation of the temporal structure of the study design.

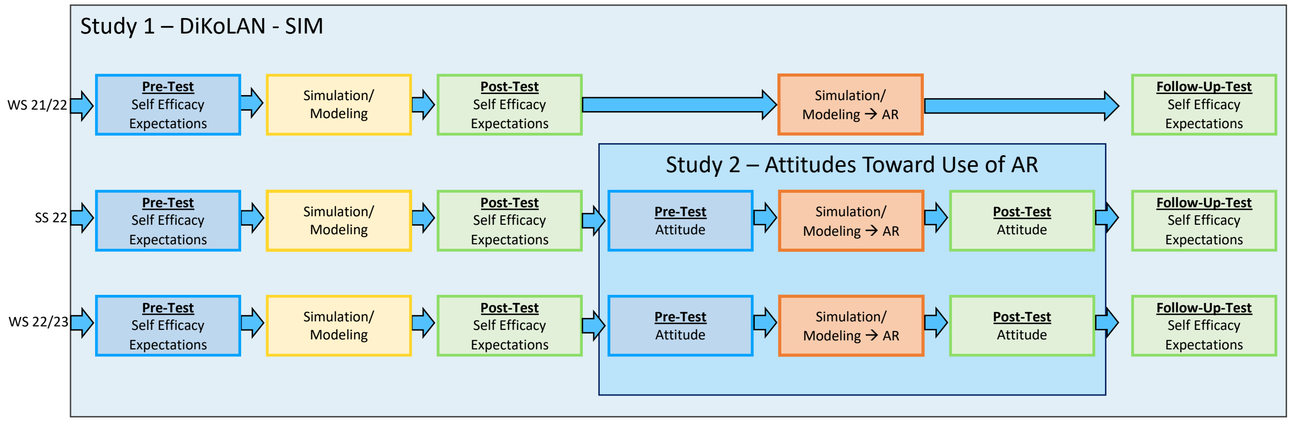

Figure 4. Design of the study. Study I—Exploring Self-Efficacy Expectations, Study II—Exploring attitudes towards AR in science education.

3.4. Course Design

The interventions presented here were carried out as part of the subject didactics seminar "Digital Competencies for Teaching in the Science Education" in the Master of Education course at the University of Konstanz and pursued the goal of promoting digital core competencies in science education (biology, physics, and chemistry) [45]. The origin of the core competencies to be taught is in the DiKoLAN competency framework [47,48], which also includes the competency area of simulation and modeling, in which the AR technology is included.

The seminar concept spans a total of 14 weeks and consists of synchronous and asynchronous components, as well as an examination phase. In the initial weeks, pre-service teachers participate in synchronous teaching–learning units, which provide an introduction to the use of digital media in science education. Subsequently, each week focuses on the instruction of one specific core competency. Following the synchronous phase of the seminar, there is an asynchronous working phase where pre-service teachers design a specific teaching–learning scenario with the assistance of individual guidance. This scenario is then presented and implemented as a sample lesson during the examination phase [45,57]. Figure 5 shows the one graphical representation of the seminar structure.

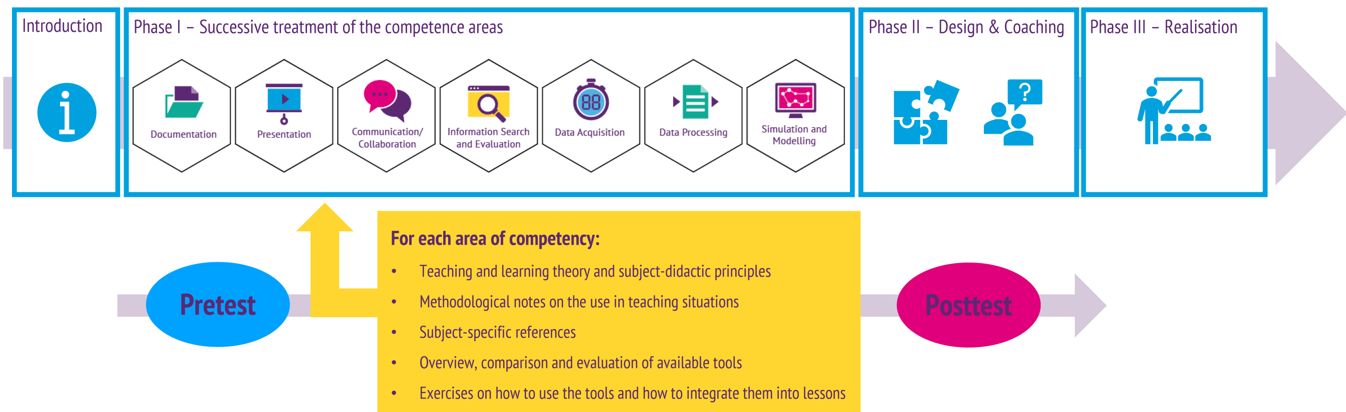

Figure 5. Structure of the seminar. Divided into the following phases: Introduction, Phase I—Successively addressing the competency areas, Phase II—Design and Coaching, Phase III—Realisation [45].

The intervention described here is part of the core competency of simulation and modeling and was conducted over two consecutive weeks, from the winter semester 21/22 to the winter semester 22/23.

In contrast to previous studies [45], all competency expectations formulated in the Simulation and Modeling competency area (Figure 2) were explicitly addressed in the two 90 min sessions.

In preparation for the pre-service teachers' active involvement with the practical application and independent design of AR applications, particular emphasis was placed on two aspects, which is why their content is highlighted here: model theory and simulations.

3.4.1. Model Theory

The goal of scientific inquiry often involves exploring complex phenomena in nature, making predictions, and solving problems. However, due to the immense complexity of certain phenomena, predictions can be extremely difficult or even impossible if all influencing variables are to be considered. As a result, researchers typically focus on specific aspects of phenomena to enable an investigation, resulting in the creation of models of those phenomena [58].

Despite the significant importance of models and the process of modeling, particularly in the field of natural sciences [59,60], there is no unified definition of the term "model" or a unified theory of modeling [60]. One possible model theory is the general model theory proposed by Stachowiak [61], which states that a model represents a reproduction of a limited segment of reality, an image of the original phenomenon. Three characteristics can be identified to characterize the relationship between the original phenomenon and the resulting model: Firstly, the representational characteristic, which expresses that models always represent a representation of an original and do not fully coincide with it. It should be noted that originals can also be considered models, and various models can describe the same original. Secondly, the abstraction characteristic describes how models never encompass all but only the most relevant features of the original for the specific application. Thirdly, the pragmatic characteristic emphasizes that models serve the purpose of replacing the original under certain conditions and for a specific inquiry.

In the field of education, models are important because they assist learners in processing information to develop flexible, transferable, and applicable knowledge. The reflective use of models serves as a key that enables a detailed understanding of scientific thinking and practices. Model competence, therefore, plays a crucial role in understanding science and has already been included as an element of the competency area "Knowledge Acquisition" in the educational standards for scientific subjects such as biology by the Standing Conference of the Ministers of Education [62].

To meet this demand, it is crucial that teachers can effectively convey model competence to learners. To ensure this, it is necessary to impart the corresponding competencies during teacher training [47].

3.4.2. Simulations

The term "simulation" can generally be defined as the reproduction of a process or situation [63], although nowadays, the term "computer simulation" is predominantly known. Despite its popularity, there is no unified definition for computer simulations [64]. However, computer simulations are commonly associated with specific attributes and features, such as the ability of a program to manipulate variables in a virtual environment, create computational representations of real or hypothetical situations, or provide dynamic and interactive visual learning experiences [65]. Another area that is partially associated with computer simulations is online labs, which enable fully virtual or remote experimentation [66,67]. For the use of simulations in schools, the definition by Vlachopoulos and Makri [68] can also be employed, stating that a simulation can be regarded as a scenario-based environment that allows students to apply their prior knowledge and practical skills to a real-world problem. This approach not only promotes existing competencies but also fosters interpersonal skills such as communication, teamwork, and leadership.

Simulations are employed in various fields. They are particularly prominent in aerospace industries [69], automotive industries [70], healthcare [71], and education [72], where learners have the opportunity to practice their skills without incurring potential risks. Simulations also facilitate conducting experiments in which learners can manipulate specific variables to verify or falsify hypotheses [73].

The design of the seminar and the selection of the content covered in it were specifically aligned with the competency areas related to simulation and modeling as outlined in the DiKoLAN framework (Figure 2).

3.4.3. Interventions

Due to the COVID-19 pandemic, the Simulation and Modeling competency area was conducted online in the winter semester 21/22. However, in the summer semester 22 and winter semester 22/23, the seminar was conducted in person, while maintaining the overall structure of the seminar across all three semesters.

The seminar is divided into two consecutive sessions, with the first session focusing on the topic of modeling and the second session addressing the area of simulation. Both sessions build upon each other, as theoretical and practical competencies related to models and modeling are required before these competencies can be applied in the realm of simulation. Therefore, in the first session, pre-service teachers create two- and three-dimensional models that can be utilized in simulations during the second session.

The basic structure of the two consecutive sessions is nearly identical and consists of an initial theory part followed by a practical phase. Within the theory part, pre-service teachers are first provided with fundamental information such as definitions, applications, and reasons for or against utilization. In the subsequent practical phase, pre-service teachers are introduced to potential software programs for creating models and simulations, where the basic processes are demonstrated initially and then repeated independently by the pre-service teachers. For this purpose, both simple programs such as Keynote or PowerPoint and significantly more complex graphic design programs such as Autodesk Maya and authoring tools [1] are utilized to create basic AR applications.

For each seminar session, a presentation was created to provide pre-service teachers with the necessary theoretical information. Various examples of self-created models and animations/simulations are demonstrated during the subsequent practical phase, allowing pre-service teachers to replicate them using the available software. Figure 6 illustrates a selection of possible models and animations/simulations that are showcased during the seminar sessions.

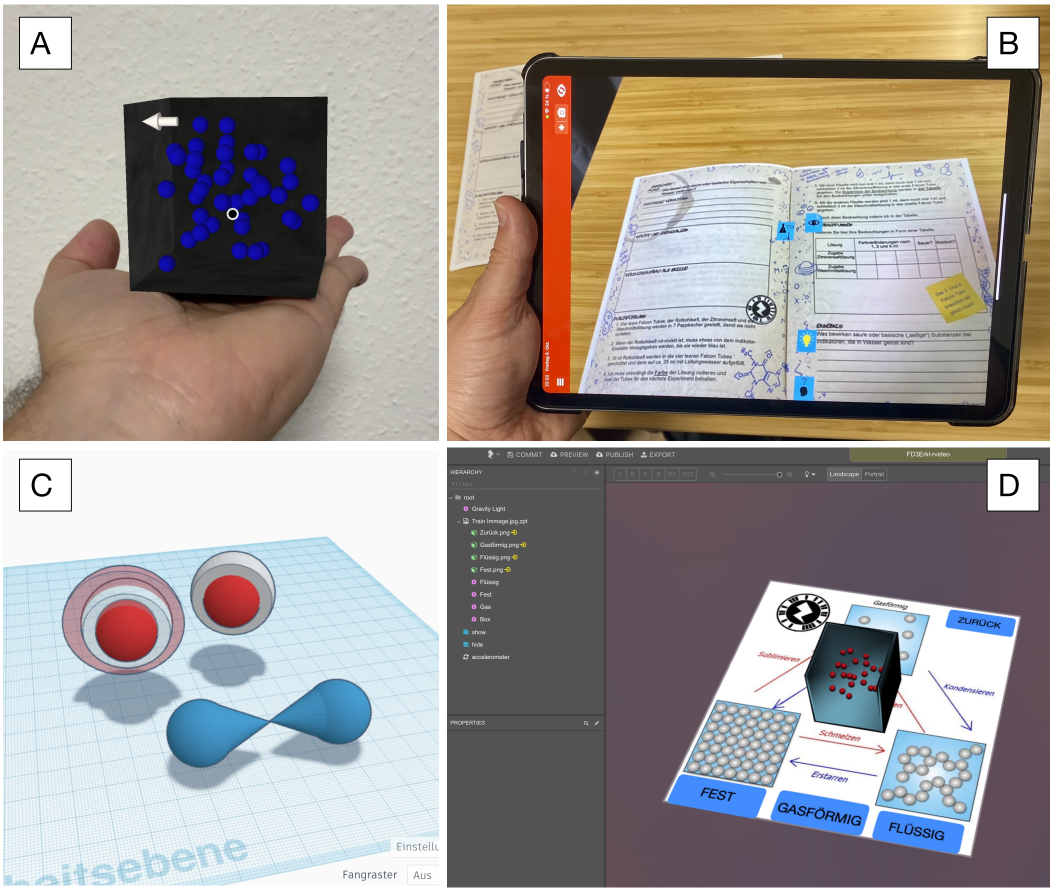

Figure 6. Overview of materials and software used in the seminar. (**A**) Undifferentiated particle model (states of matter), (**B**) application area for AR to support paper-based learning, (**C**) creation of simple three-dimensional models using Tinkercad [74], (**D**) creation of AR applications using ZapWorks Studio [75].

3.5. Statistical Analysis

The study was conducted with $n = 29$ pre-service teachers in the case of the first questionnaire on self-efficacy expectations and with $n = 15$ pre-service teachers in the case of the second questionnaire on attitudes towards AR in STEM education. In the case of the first questionnaire, data collection took place one week before and one week after the intervention. The second questionnaire, to determine attitudes toward AR in STEM education, was completed at the beginning and end of each intervention session.

Statistical analysis of the collected data was performed using the statistical software R [76]. To examine the data collected, reliability analyses were first conducted to test the internal consistency of the two questionnaires.

To examine the data from the first questionnaire, scales of all competence areas and their mean values were formed, whereby the mean difference represents a central measurement variable for determining the effectiveness of the intervention measure. The statistical investigation of the mean values was first carried out using a repeated measures ANOVA and post hoc *t*-tests to compare the pre- and post-tests. To further the investigation, a Wilcoxon signed-rank test was subsequently conducted to test each pre-test/post-test Item pair for growth in means.

For the examination of the data from the second questionnaire, scales were also formed first. In this case, the data were divided into three groups related to the achievement of competencies that were classified as either major goals, minor goals, or unaddressed goals. The resulting scales were analyzed using Wilcoxon signed-rank tests. In the following, the data are explained in more detail with the help of the corresponding tables and charts.

4. Results

4.1. Study 1—Increase in DiKoLAN-Related Self-Efficacy Expectations

In order to obtain an overview of the mean increase achieved in the digitization-related self-efficacy expectations in the addressed competency area *Simulation and Modeling* and to determine the influence of the intervention on the self-efficacy expectations mentioned, a scale is first formed from the corresponding items. Since in the first sub-study all competency expectations mentioned in the competency area "Simulation and Modeling" of the DiKoLAN framework were addressed, all corresponding test items in the pre-test and post-test are combined to one 24-item scale "Simulation and Modeling" covering all technology-related facets of the TPACK framework. The scale shows perfect scale reliability in the pre-, post- and follow-up tests with Cronbach's $\alpha_{\text{pre}} = 0.976$ in the pre-test, $\alpha_{\text{post}} = 0.972$ in the post-test, and $\alpha_{\text{follow-up}} = 0.974$) in the follow-up test, with mean values before ($M_{\text{pre}} = 3.15$, $SD_{\text{pre}} = 1.001$) and after the intervention ($M_{\text{post}} = 4.82$, $SD_{\text{post}} = 1.228$) as well as in the follow-up test ($M_{\text{follow-up}} = 5.11$, $SD_{\text{follow-up}} = 1.187$).

A repeated measures ANOVA was performed to compare the effect of time on self-efficacy expectations. There was a statistically significant difference in self-efficay expectations between at least two groups ($F(2, 1) = 77.75$, $p < 0.001$). Pairwise t-tests were performed to compare the effect of time on self-efficacy expectations between times. The p-values were adjusted using the Benjamini–Hochberg procedure [77]. There was a significant increase in the digitalization-related self-efficacy expectations in the area of competencies "Simulation and Modeling" after the intervention ($M_{\text{post}} = 4.82$, $SD_{\text{post}} = 1.228$) compared to before the intervention ($M_{\text{pre}} = 3.15$, $SD_{\text{pre}} = 1.001$), $t(27) = 6.38$, $p < 0.001$, $d = 1.20$. There was a significant increase in the digitalization-related self-efficacy expectations in the area of competencies "Simulation and Modeling" in the follow-up test ($M_{\text{follow-up}} = 5.11$, $SD_{\text{follow-up}} = 1.187$) compared to after the intervention ($M_{\text{post}} = 4.82$, $SD_{\text{post}} = 1.228$), $t(27) = 2.17$, $p = 0.020$, $d = 0.41$. There was also a significant increase in the digitalization-related self-efficacy expectations in the area of competencies "Simulation and Modeling" in the follow-up test ($M_{\text{follow-up}} = 5.11$, $SD_{\text{follow-up}} = 1.187$) compared to before the intervention ($M_{\text{pre}} = 3.15$, $SD_{\text{pre}} = 1.001$), $t(27) = 7.35$, $p < 0.001$, $d = 1.39$. Figure 7 summarizes the results.

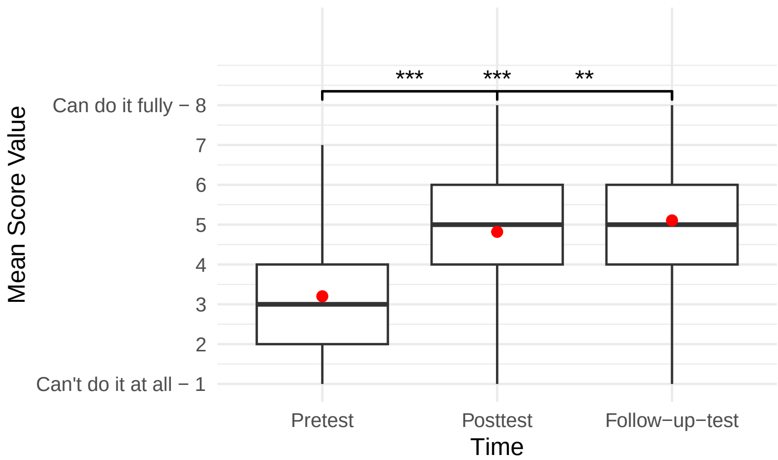

Figure 7. Comparison of the mean scores of the pre-test, post-test and follow-up test.The red dots show the group means. p values: *** $p < 0.001$, ** $p < 0.01$.

For a more in-depth analysis of whether digitization-related self-efficacy expectations could actually be promoted for all addressed competency expectations, pairwise comparisons of pre- and post-test results were performed for all test items using Wilcoxon signed-rank tests. Table 1 shows the results of the Wilcoxon signed-rank tests for competency expectations hypothesized to increase over the intervention (p-values adjusted following the Benjamini–Hochberg procedure [77]).

Table 1. Results of Wilcoxon signed-rank tests for simulation and modeling competency expectations hypothesized to increase during intervention. Adjusted *p*-values (Benjamini–Hochberg procedure). S: Special Tools, C: Content-specific Context, M: Methods/Digitality, T: Teaching; N: Name, D: Describe, A: Use/Apply.

	Pre-test			Post-test						
Item	*n*	*M*	*SD*	*n*	*M*	*SD*	*V*	*p*	*r*	**Hyp.**
SIM.S.N1	18	4.00	1.46	28	5.82	1.81	136.0	<0.001	0.87	accept
SIM.S.N2	18	3.06	1.55	28	4.57	1.67	117.0	<0.001	0.79	accept
SIM.S.N3a	18	2.94	1.55	28	4.79	1.64	132.0	<0.001	0.79	accept
SIM.S.N3b	18	3.22	1.35	28	5.00	1.52	129.5	<0.001	0.78	accept
SIM.S.N4	17	3.12	1.36	28	5.18	1.42	118.5	<0.001	0.83	accept
SIM.S.D1	18	2.83	1.58	27	3.93	1.44	113.0	0.0021	0.72	accept
SIM.S.A1	18	2.67	1.46	27	4.70	1.81	134.0	<0.001	0.83	accept
SIM.C.N1	18	3.67	1.64	27	5.41	1.89	145.5	<0.001	0.78	accept
SIM.C.N2	18	3.50	1.65	27	5.41	1.76	134.5	<0.001	0.84	accept
SIM.C.N3	18	3.11	1.49	27	4.52	1.53	91.0	<0.001	0.81	accept
SIM.C.N4	18	4.06	1.86	27	5.22	1.69	82.0	0.0054	0.62	accept
SIM.C.N5	18	3.56	1.58	27	4.93	1.49	110.0	0.0026	0.69	accept
SIM.C.D1	18	3.22	1.59	28	4.57	1.57	89.5	0.0021	0.75	accept
SIM.M.N1a	18	3.39	1.33	28	5.00	1.36	136.0	<0.001	0.87	accept
SIM.M.N1b	18	2.89	1.53	28	4.82	1.25	168.5	<0.001	0.86	accept
SIM.M.N1c	18	3.00	1.33	28	5.07	1.39	136.0	<0.001	0.87	accept
SIM.M.N2	18	3.33	1.81	27	5.07	1.73	114.5	0.0021	0.76	accept
SIM.M.D1	18	2.89	1.71	28	4.89	1.57	150.0	<0.001	0.84	accept
SIM.M.D2	18	3.28	1.90	27	4.81	1.64	157.5	<0.001	0.75	accept
SIM.T.N1	18	3.39	1.42	28	4.68	1.59	113.0	0.0021	0.72	accept
SIM.T.D1a	18	3.17	1.58	28	4.68	1.36	111.0	0.0024	0.70	accept
SIM.T.D1b	18	3.00	1.53	28	4.39	1.50	112.5	0.0021	0.72	accept
SIM.T.A1a	18	2.78	1.66	28	4.18	1.52	125.5	0.0021	0.70	accept
SIM.T.A1b	18	2.78	1.70	28	4.04	1.62	127.0	0.0021	0.71	accept

According to Cohen, effect sizes determined as correlation coefficient *r* can be roughly interpreted as follows: 0.10 → small effect, 0.3 → medium effect, and 0.50 → large effect [78] (p. 532). However, it must be kept in mind that the interpretation of effect sizes should always depend on the context [78].

4.2. Study 2—Increase in AR-Related Self-Efficacy Expectations

The responses were analyzed using R statistical software [76]. Means and standard deviations were computed for each item in the pre-tests and post-tests. Wilcoxon signed-rank tests were conducted for each pre-test post-test item pair to test for growth in item means. The results of the descriptive and inferential statistics are listed in Tables 2 and 3.

Table 2 shows the scales.

Table 2. Scale reliabilty. ATT: attitudes towards learning with AR in the classroom, MOT: motivational orientation to the use of AR in the classroom, SUB: subjective norm expectations for the use of AR, SEE: self-efficacy expectations on the use of AR, CON: perceived constraints to the use of AR.

Scale	**Items**	α_{pre}	α_{post}
ATT	ATT01, ATT04–ATT08, ATT10	0.678	0.700
MOT	MOT01–06	0.857	0.886
SUB	SUB01–06	0.694	0.850
SEE	SEE01–08, SEE01 and SEE04 inverted	0.835	0.880
CON	CON1–3, CON03 inverted	0.643	0.661

Table 3 shows the results of Wilcoxon signed-rank tests for competency expectations hypothesized to increase over intervention II with large effect sizes. Adjusted *p*-values (Benjamini–Hochberg procedure) [77].

Table 3. Results of Wilcoxon signed-rank test for scores on items primarily addressed and hypothesized to increase during intervention II. Adjusted *p*-values (Benjamini–Hochberg procedure). ATT: attitudes towards learning with AR in the classroom, MOT: motivational orientation to the use of AR in the classroom, SUB: subjective norm expectations for the use of AR, SEE: self-efficacy expectations on the use of AR, CON: perceived constraints to the use of AR. * Negatively formulated scale, therefore the mean values are inverted.

	Pre-test			Post-test						
Item	*n*	*M*	*SD*	*n*	*M*	*SD*	*V*	*p*	*r*	**Hyp.**
ATT	28	3.08	0.28	28	3.20	0.28	270.5	0.02	0.49	accept
MOT	28	2.79	0.51	28	3.19	0.54	255.0	<0.001	0.75	accept
SUB	28	1.80	0.38	28	1.79	0.45	46.5	0.49		reject
SEE	28	2.42	0.40	28	2.75	0.42	383.0	<0.001	0.78	accept
CON *	28	1.67	0.41	28	1.71	0.39	30.0	0.30		reject

5. Discussion

The digitalization of everyday school life has become an important aspect for all teachers. In Germany, this is especially true since the publication of the strategy of the Standing Conference of the Ministers of Education and Cultural Affairs of the Länder in the Federal Republic of Germany 'Education in the Digital World' in 2016, which called for the acquisition of digital competencies by students [79]. However, to promote these competencies, it is essential that the teachers who are supposed to impart them also possess likewise competencies themselves. Several studies have suggested that even individuals commonly referred to as "digital natives," who have been raised in the era of digital media and the Internet, do not inherently possess the requisite knowledge and skills [80–82].

Furthermore, it has been found that the digital infrastructure in schools often lags behind the required standards [43], and mandatory offerings for acquiring (digital) media literacy have only been partially introduced at universities. According to a study by "Monitor-Lehrerbildung (monitor teacher education)" [83] (p. 2), from 2022, the percentage of universities that have introduced mandatory offerings for acquiring digital media competencies during pre-service teacher training is still not sufficent (63.6% in primary education, 60.5% in lower secondary education, 50% in upper secondary/general education, 56.2% in upper secondary and vocational education, and 52.2% in special education). The first goal of this paper is to present the concept and evaluation of two seminar units, which are located in the area of the digital core competence simulation and modeling, from the DiKoLAN competence framework. These interventions are used in the context of a seminar on science education for pre-service teachers in the Master's program. This seminar aims to teach digital core competencies and thus makes an important contribution to promoting the media competence of pre-service teachers. This has already been described by other studies as a significant part of the education of pre-service teachers [84] and as an essential part of the media education of students [85].

While the first of the two seminar units deals with the topic area of models and modeling, the second seminar unit includes the topic area of simulation, in which the future technology augmented reality can be integrated. This technology has the potential to be of particularly high value both in industry [41,42] and in the field of education [6,86–88]. To determine the effectiveness of the seminar, the self-efficacy expectations of the pre-service teachers were examined using an online questionnaire within a pre–post-follow-up design.

The second goal of the work is to investigate the effects of the seminar unit on the topic of simulation and the AR technology used in it in terms of changing the attitudes of the pre-service teachers towards the use of AR in science education. This is significant in the sense that the attitudes towards the use particularly represent one of the most important predictors when it comes to the future use of AR in the classroom by the pre-service teachers [89]. For this purpose, a questionnaire based on the theory of planned behavior was used, which was completed in a before-and-after design immediately before and after the intervention, respectively.

Within the framework of the research, two research questions and the corresponding hypotheses were formulated, which will be answered within the framework of this discussion and on the basis of the previously presented results.

The first research question (RQ1) addressed whether a 90 min intervention on prospective teachers' digital competencies in simulation and modeling can significantly affect pre-service teachers' self-efficacy expectations. Previous studies have shown that similar intervention measures can have a significant positive effect on self-efficacy expectations in the area of digital competencies [90,91]. Similar results were found by studies that also dealt with the DiKoLAN competency framework and were able to positively influence some competency expectations through an intervention [45]. Based on these results, we hypothesized for this study that an intervention that addressed all of the competency expectations in the Simulation and Modeling domain of the DiKoLAN competency framework would also have significant positive effects in all of the competency expectations. This results in the formulation for Hypothesis H1: the developed intervention concerning pre-service teachers digital competencies in the area Simulation and Modeling has a strong positive effect on participants' respective self-efficacy expectations.

Based on the results already presented, hypothesis H1 can be confirmed. The examination of pre-service teachers' self-efficacy expectations revealed strong positive effects (r from 0.62 to 0.87) and a significant positive increase in measured mean scores ($M_{\text{pre}} = 3.15$, $SD_{\text{pre}} = 1.001$; $M_{\text{post}} = 4.82$, $SD_{\text{post}} = 1.228$; $M_{\text{follow-up}} = 5.11$, $SD_{\text{follow-up}} = 1.187$) for all competency expectations in the area of simulation and modeling. Thus, the first research question, RQ1, can also be answered with the statement that the intervention has a significant positive effect on the self-efficacy expectation of the pre-service teachers in all competency expectations in the area of simulation and modeling. These results are also aligned with previous research findings, which also show that digital media interventions can have a positive impact on pre-service teachers' self-efficacy expectations [92,93].

The second research question (RQ2) addresses whether a 90 min intervention session can significantly influence prospective teachers' attitudes towards the use of AR in science education. Here, some evidence could be found from the existing literature that training on the use of AR, especially with practical exercises on the use of the technology, has a positive effect in the area of attitudes towards the use of AR [94–96]. Based on this literature, which showed that pre-service teachers' attitudes towards digital media in STEM education can be positively influenced using intervention measures, we formulated Hypothesis H2: the developed intervention will have a strong positive effect on pre-service teachers' attitudes towards the use of AR in science education.

The results of the study show that hypothesis H2 can only be partially confirmed. While the results of the constructs MOT and SEE showed both strong effects ($r_{\text{SEE}} = 0.78$; $r_{\text{MOT}} = 0.75$) and significant positive increases in mean scores (MOT: $M_{\text{pre}} = 2.79$, $SD_{\text{pre}} = 0.51$; $M_{\text{post}} = 3.19$, $SD_{\text{post}} = 0.54$; SEE: $M_{\text{pre}} = 2.42$, $SD_{\text{pre}} = 0.40$; $M_{\text{post}} = 2.75$, $SD_{\text{post}} = 0.42$), only a very close strong positive effect ($r_{\text{ATT}} = 0.49$) was found for the construct ATT. However, the measured mean values also show a significant positive increase (ATT: $M_{\text{pre}} = 3.08$, $SD_{\text{pre}} = 0.28$; $M_{\text{post}} = 3.20$, $SD_{\text{post}} = 0.28$). In addition to this, it should be noted that already the mean value of the pre-test can be considered as very high and a significant improvement; therefore, it proves not to be so easy. In the area of the constructs SUB and CON, Hypothesis H2 must be rejected. Here, no significant effects or significant positive changes of the mean values could be found. Therefore, the research question RQ2 can be answered in such a way that the conducted intervention could influence the attitudes of pre-service teachers only in the areas ATT, MOT, and SEE significantly, and in the area ATT, only just, positively.

Limitations

The findings from this study show that the presented intervention has the potential to significantly positively improve self-efficacy expectations within the addressed competency expectations. At the same time, it was found that attitudes towards the use of AR in science education, in some areas, could also be positively influenced. In addition to these findings, however, it must be noted that the intervention was not able to achieve improvements in the areas of subjective norm expectations and expected difficulties in the use of AR. This can be interpreted to mean that, even after the intervention, pre-service teachers did not anticipate the use of AR by future supervisors or peers, or anticipated fewer difficulties in using AR as a technology. However, attitudes toward learning with AR, motivation to use AR in their own teaching, and most importantly, self-efficacy expectations toward the use of AR were significantly improved, giving hope that pre-service teachers who undergo this intervention will use AR themselves in the future and be motivated to continue to engage with this topic. In addition to all the findings of this study, it must of course be noted that the study took place with a severely limited number of participants, which prevents generalization of the results. It is also worth noting that the study, especially in the area of attitudes toward the use of AR in science education, only examined short-term effects, immediately following the intervention session. Future research could investigate long-term effects and the transferability of the results to a larger sample.

6. Conclusions

In summary, the interventions presented in this publication represent a useful and effective method to enhance pre-service teachers' digital competencies. The present study illustrates that these interventions have the potential to significantly improve self-efficacy expectations in the area of the core digital competency of simulation and modeling, while positively influencing attitudes toward the use of augmented reality in science education. This suggests that these types of intervention sessions can be considered effective interventions for increasing media literacy among teachers and provide an opportunity to introduce AR technology into the education field by allowing prospective teachers to serve as future multipliers in schools. Nevertheless, further research is needed to examine the long-term effects of these interventions and to extrapolate the results to a larger sample, which will provide a more comprehensive understanding of the effectiveness of these interventions.

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Institutional Review Board Statement: All participants were students at a German university. They took part voluntarily and signed an informed consent form. Pseudonymization of participants was guaranteed during the study. Due to all these measures in the implementation of the study, an audit by an ethics committee was waived.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author. The data are not publicly available due to the ongoing study.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Questionnaire "Augmented Reality (AR) in science education". * Negatively formulated items.

Item	Itemtext
Attitudes towards learning with Augmented Reality (AR) in the classroom (ATT)	
ATT01	Augmented Reality should generally be given significant emphasis in school curricula.
ATT02 *	The use of Augmented Reality in schools leads to a flattening of the level of instruction.
ATT03 *	Negative consequences of Augmented Reality for learning are underestimated.
ATT04	The use of Augmented Reality enables a high degree of self-directed learning.
ATT05	Through the use of Augmented Reality, students can be better motivated to learn.
ATT06	Computers and Augmented Reality open up opportunities for creativity in learning.
ATT07	The use of Augmented Reality in schools ensures that children are well-prepared for their professional lives.
ATT08	Learning with Augmented Reality is an efficient form of learning.
ATT09	With Augmented Reality, I can plan and adapt lessons more effectively for the target audience.
ATT10	Augmented Reality allows for higher student engagement.
Motivational orientation to the use of Augmented Reality (AR) in the classroom (MOT)	
MOT01	It brings me joy to think about how I can use Augmented Reality in the classroom.
MOT02	Even in my free time, I research the possibilities of incorporating Augmented Reality into teaching.
MOT03	I enjoy familiarizing myself with the operation of Augmented Reality for teaching.
MOT04	I am willing to invest some extra time in lesson preparation if it allows me to use Augmented Reality in the classroom.
MOT05	I am very excited to consider how I can better support my students' learning with the help of Augmented Reality.
MOT06	Selecting or creating Augmented Reality for teaching is one of the most interesting parts of lesson preparation.
Subjective norm expectations for the use of AR (SUB)	
SUB01	The curriculum demands the use of Augmented Reality.
SUB02	Students value the use of Augmented Reality in the classroom.
SUB03	My fellow students believe that Augmented Reality is an essential element of contemporary teaching.
SUB04	Supervisors expect the use of Augmented Reality during teacher training.
SUB05	Lecturers in my teacher education program consider it important to use Augmented Reality in teaching.
SUB06	Teachers in schools believe that Augmented Reality must be part of instruction.
Self-efficacy expectations on the use of Augmented Reality (AR) (SEE)	
SEE01 *	I will find it difficult to conduct experiments using Augmented Reality in the classroom.
SEE02	I am confident in creating Augmented Reality for my teaching.
SEE03	I am certain that I can implement Augmented Reality-based experiments in the classroom.
SEE04 *	I find it challenging to explain to my students how to operate Augmented Reality.
SEE05	All in all, it is very easy for me to incorporate suitable Augmented Reality into lesson planning.
SEE06	Modeling a phenomenon or process in the classroom using Augmented Reality is not difficult for me.
SEE07	I am generally capable of purposefully using Augmented Reality applications in teaching.
SEE08	I know how to design lessons in which students can learn to create Augmented Reality.
Perceived constraints to the use of AR (CON)	
CON01 *	The lengthy preparation time often prevents me from incorporating Augmented Reality.
CON02 *	The high technical effort often prevents me from incorporating Augmented Reality.
CON03	The equipment in schools allows for seamless integration of Augmented Reality into lesson planning.
CON04 *	Sometimes I lack the necessary knowledge to incorporate Augmented Reality into lesson planning.
CON05	It heavily depends on the discipline of the students in class whether I incorporate Augmented Reality into lesson planning.
CON06	I often have ideas for the use of Augmented Reality.

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