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The Impact of Student Characteristics for Working with AR Technologies in Higher Education—Findings from an Exploratory Study with Microsoft HoloLens

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Abstract: Augmented reality (AR) is being used in various fields and increasingly being used in the educational sector. Although there is still little research available on the use of this technology in education, the research literature indicates its potential and effectiveness. However, information about students' characteristics and individual learning preconditions in relation to learning with AR technologies is still scarce. In this study, 18 student teachers for science and technology for lower secondary schools of a German-speaking university of teacher education were asked about different aspects related to motivation, interest, attitude, and self-efficacy before (questionnaire) and after (interviews) participating in an AR-supported teaching unit with Microsoft HoloLens. The results show that the students have a very positive attitude towards AR technologies and were highly motivated to work with this technology. Attitudes towards AR technologies, as well as towards new technologies in general, were found to be related to motivational factors and aspects of self-efficacy in the context of the AR teaching unit. As these aspects can have an impact on learning outcomes, it is of utmost importance to understand and recognize them. Educators and researchers should therefore pay more attention to these issues in the future.

Keywords: augmented reality (AR); teacher education; student teachers; student characteristics; explorative study; Microsoft HoloLens

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1. Introduction

Teaching and learning are complex processes. These have been investigated in various studies over the past decades and described in theoretical models. The relationship between instructional processes, learning products, context, and prerequisites has very often been represented in so-called process–product models of teaching and learning. The underlying assumption of these models is that good quality teaching processes lead to positive learning outcomes for students. Based on this work, as well as on current research findings, these models were adapted continuously and became more and more differentiated. Today, "supply-use-models" (see Figure 1) serve as the basis of contemporary instructional effectiveness research [1]. These models take into account that teaching does not merely affect students' learning and learning outcomes in a causal one-directional way. According to current knowledge, learning outcomes are determined by multiple conditions and complex interactions [2]. Thus, the quality of classroom processes depends on characteristics and the qualifications of the teacher. On the other hand, individual learning processes are moderated by student characteristics and individual learning preconditions (e.g., cognitive and motivational aspects). Other moderating factors are class context (e.g., class size) and the learning environment, such as the influence of peers and of media.

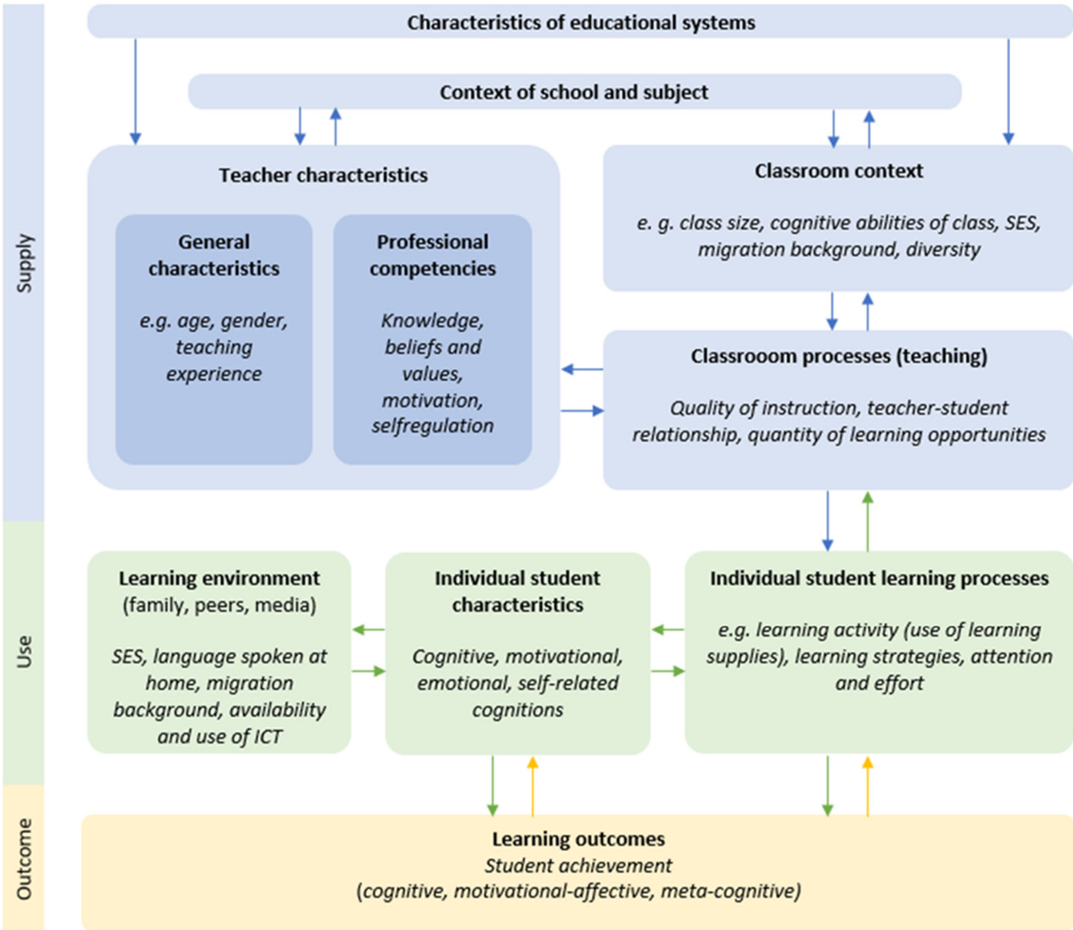

Figure 1. Multilevel supply-use-model adapted from Brühwiler and Blatchford [2] and Seidel [1].

In terms of the *learning environment*, a lot has changed in the last few decades. The availability of computers, laptops, and mobile phones, as well as the development of other technologies and various software and applications, has created new opportunities for teaching and learning. However, use of media that is not based on pedagogical considerations often does not change practice and does not improve student learning [3]. To guide teachers on how to successfully integrate technology into the classroom, researchers have developed standards, frameworks, models and theories which can serve as a basis for practitioners in enriching teaching and learning through the integration of technology [4].

One technology that has received increasing attention in education in recent years is augmented reality (AR). Although the development of the first AR application intended exclusively for use in educational institutions was made 25 years ago [5], the technology has become widespread mainly in the last few years due to the accessibility of smartphones and tablets. The production of AR-specific devices such as smart glasses (e.g., Google Glass or Microsoft HoloLens) has further increased the interest in this technology [6]. Today, AR applications are successfully used at different educational levels, in different educational settings, and in different environments, offering many possibilities and numerous benefits to learners [5].

AR refers to a direct or indirect view of a physical, real environment that has been enhanced by adding virtual computer-generated information. While virtual reality (VR) technology completely immerses the user in a synthetic world without the user being able to see the real world anymore, AR technology enhances the sense of reality by superimposing virtual objects, information, and cues (text, audio, images, video, 3D objects) on the real world in real time [7–9]. Various studies have already explored the possibilities that the use of AR offers for teaching and learning. In recent years, the findings have been summarized in various literature studies and meta-analyses (e.g., [10–15]). These studies demonstrate that the use of AR in education offers many advantages to support learning, and this new technology is consistently seen as having an enormous potential. The results show that AR can support kinesthetic learning, visual and spatial imagination [16,17], and promote learners' willingness to engage with scientific topics, as well as motivation and interest in general. It was reported that learners attribute more relevance to the learning activities, gain more confidence in engaging with the learning activities, pay more attention, and experience more satisfaction and enjoyment [10,18–20]. Furthermore, AR increases collaboration among learners and between learners and teachers. This also enhances critical thinking, problem solving, information processing and communication skills, and improves learning transfer (e.g., [6,10,17,21–24]).

As previously outlined, learning effects are moderated by *student characteristics* and *individual learning preconditions*. "Every learner is a unique individual with unique characteristics that include strengths and challenges. Understanding both and responding with skill and sensitivity allows the education system to support all learners in reaching their full potential" [25]. Teachers should therefore strive to create classrooms where the unique identity of each learner is addressed, and their individual characteristics are valued and supported. When working with digital media in the classroom, it is important that the associated preconditions of the learners are taken into account. Particularly with newer technologies, with which learners are not yet accustomed, cognitive, motivational, or emotional preconditions can have a significant impact. This aspect is often disregarded since nowadays, only so-called 'millennials' attend higher education institutions. According to Pedró [26], millennials are those "generations born from the 1980s on and grown in a context where digital technologies form inextricably part of their daily lives". They are said to be skilled in using computers, creative in using technology and, above all, very adept at multitasking [26]. Accordingly, educators assume that learners can easily handle digital technologies and use them to support their learning. Recent studies show, however, that the skills of millennials do not quite match this expectation. There are reports that individuals from this generation hardly use any technologies and that they tend to be a rather non-homogeneous group of individuals who are fundamentally different in terms of technology-related characteristics. The differences can be explained based on their national culture, their year of study and their experience with technology (computers, tablets and the internet) [27]. Studies have also revealed that students' digital literacy is more focused on consumption than production. Although learners use social media and the internet extensively in their leisure time, their use of digital resources and digital technologies in learning contexts is not particularly advanced [28]. This is also reflected to some extent in recent studies on the use of AR technologies in learning settings. Challenges identified include in particular usability, technical problems regarding the implementation, tracking and calibration problems, and mobility problems when used outdoors [10,24]. In addition to technical challenges, cognitive load [29] is frequently addressed on the side of the learners. Furthermore, learners mentioned that AR systems require too much attention due to their multitasking nature, and are therefore regarded as a possible factor of distraction [13].

However, knowledge in this area is still very limited. Little is known about student characteristics and individual learning preconditions in relation to learning with AR technologies. Yet, as outlined above, these factors are significant and can have a considerable impact on learning outcomes. If the technology is to be successfully integrated into educational settings to maximize the benefits for learners, the focus should not only be on the supply, but also on the use and thus on learners' prerequisites in relation to the technology.

Based on this background, the research project "Augmented Reality in Teacher Education. An exploratory study using HoloLens in Science Education" (ALex) was conceptualized and carried out. The aim of the study was to design an AR-supported teaching unit and to implement it with students in a University of Teacher Education. The experiences and results of the study should provide information on the possibilities, opportunities, and challenges of using augmented reality (AR) in teacher education in the subject of science and technology. The study was conducted with Microsoft HoloLens, an augmented reality headset that is placed on the head as with conventional glasses and acts as a head-mounted display (for more information on the study see [30]). Based on the theoretical considerations, the study aims to provide more information about student characteristics and individual learning preconditions in relation to learning with AR technologies. The following research questions (RQ) are being pursued in this regard and will be addressed in this paper:

RQ1: What previous experience and attitude towards AR technologies do students at a University of Teacher Education have?
RQ2: To what extent is the attitude towards AR applications of the students related to the current motivation to complete the AR-based learning task?
RQ3: How motivated are the students to engage with the topic and the technology, and how is this related to other student characteristics?
RQ4: What is the level of student commitment to technology and how is this related to other student characteristics?

The results of the study show that the students generally have a positive attitude towards AR technologies and were interested and motivated to participate in the AR-supported teaching unit. The majority of the students also report that their motivation has increased through working with the AR application. However, the students have hardly had any experience with this technology so far. From the written survey, it can be concluded that attitudes towards AR technologies, as well as towards new technologies in general, are related to motivational factors and aspects of self-efficacy in the context of the AR-supported teaching unit. Students who are more critical of AR and digital technologies in general are also less interested and motivated to work with it and are less confident that they will be successful with the technology and the task. Furthermore, female students are much more likely to fear negative consequences when using technology than male students. As these aspects can have an impact on learning outcomes, it is very important to be aware of and to understand them. In educational and research contexts, more attention should therefore be given to these issues in the future.

2. Materials and Methods

2.1. Participants

Student teachers of science and technology for secondary level I (grades seven to nine) of various courses at a University of Teacher Education in German-speaking Switzerland were informed about the research project and invited to participate voluntarily. A total of 20 students came forward, of whom 18 eventually participated. All students were attending a master's program, which usually takes nine semesters to complete. At the time of the project implementation, the group consisted of 10 male and 8 female students, 2 of whom were in their second semester, 11 in their fourth semester, and 5 in their eighth semester.

2.2. Research Design

The teaching unit and the associated data collection were carried out in four groups. The students were offered different dates in May 2019 for this purpose. On three dates four students were present, and on one date six students were present. Each session lasted approximately 2 h and included the following activities:

- An introduction to the content of the teaching unit by means of a short presentation (approx. 10 min);
- A written paper-based survey of the participants' characteristics (approx. 10 min);
- An introduction to the handling of the HoloLens (10–15 min);
- A work phase with the HoloLens in groups of two to three participants depending on the work task (15–20 min);

- A final survey of the participants' experiences and evaluations based on individual interviews (15–30 min).

2.3. Data Collection

All data collection was carried out by members of the project team at each of the four data collection dates. The written paper-based survey was conducted as a paper-pencil test. The test sheets were distributed to the participants and subsequently recollected, ensuring that all questionnaires of the 18 participants were received. The questionnaire was designed to capture the participants' prior experience, motivation, and interest. It contained a total of 51 questions, consisting of 33 closed-ended questions from validated questionnaire instruments, as well as 18 self-constructed, mostly closed-ended questions and a final open-ended question to allow for open-ended supplementary comments (As the study was conducted at a university in the German-speaking part of Switzerland, all questions were asked in German. Likewise, the validated questionnaires used were originally in German. All scale names and questions mentioned in this paper have been translated into English by the authors). In addition, a few general questions were asked to gain general information about the person.

The first 22 questions were asked to capture current motivation and current attitude toward the task. Eighteen questions of these were taken from the instrument "QCM: Questionnaire on Current Motivation" [31]. This instrument measures four components of current motivation in (experimental) learning and performance situations, namely fear of failure, probability of success, interest, and challenge. Another 12 questions were taken from the questionnaire "TB: Technology Commitment" [32]. The questionnaire includes the following subscales: acceptance of technology, positive technology consequences, and negative technology consequences. The third validated instrument included in the questionnaire is the general self-efficacy short scale (ASKU: Short Scale for Measuring General Self-efficacy Beliefs) [33]. The scale consists of three items only and measures the general self-efficacy expectations (that is, the appraisal of one's own competences to plan and execute actions successfully in order to achieve desired goals).

The 18 self-constructed questions were mainly related to eliciting students' previous experiences with AR applications and related attitudes. Four questions were asked about the participants' current motivation specific to the content of the study, six questions were asked about previous experience and attitude to AR applications, one question was asked to find out whether people had already used HoloLens, two general questions were asked about the topic, and with four questions the students were asked about their level of knowledge on the subject matter. As mentioned above, the last open-ended question allowed participants to comment on anything they wanted.

The introduction to the operation of the HoloLens and the subsequent work phase with the HoloLens in the groups were recorded by two stationary cameras in the room. In addition, the video and audio recordings from the head-mounted displays were saved after each work phase. Figure 2 provides an insight into the collaborative work phase with the HoloLens.

After the participants completed the work phase in the groups, they were asked about their experiences in the group work, their motivation, and their interest in individual interviews using a semi-structured interview. The interviews were recorded using audio recording devices.

Figure 2. Collaborative work phase with HoloLens (for more information on the content and structure of the teaching unit see [30]).

2.4. Data Analysis

The results of the *paper-based survey* were transferred into SPSS. Using the statistical analysis software SPSS, the data were analyzed on a descriptive basis and factor analyses and correlations were calculated. The effect sizes were interpreted according to Cohen's [34] guidelines. For most scales, a satisfactory level of alpha 0.70 was found [35]. For some scales, however, the levels are lower (see Table 1). As this mainly concerns scales from validated questionnaire instruments, these scales were nevertheless used for further calculations. Table 1 gives an overview of the questionnaires used in the paper-based survey, the scales and scale values as well as sample items (A detailed overview of the questionnaires is provided in Appendix A). One question that concerned finding out whether people had already used HoloLens, and two general questions about the topic, were not included in the data analysis (and are therefore not listed in the table). Furthermore, one item from the questionnaire on current motivation (QCM) was excluded to improve the reliability of the scale "challenge".

Table 1. Overview of the questionnaires and scales used in the paper-based survey.

Questionnaire and Scales Contained Therein	Cronbach's Alpha	Number of Items
Questionnaire on Current Motivation (QCM) *Likert scale: 1 = Disagree to 7 = Agree*		**17** [1]
Scale: Fear of failure *Sample Item: When I think about the task, I feel somewhat concerned.*	α = 0.848	5
Scale: Probability of success *Sample Item: I think I am up to the difficulty of this task.*	α = 0.743	4
Scale: Interest *Sample Item: I would work on this task even in my free time.*	α = 0.809	5
Scale: Challenge *Sample Item: This task is a real challenge for me.*	α = 0.432	3 [2]
Current motivation specific to the content of the study (own items) *Likert scale: 1 = Not motivated at all to 10 = Very motivated* *Sample Item: Please indicate on a scale of 1–10 how motivated you are to participate in this teaching unit.*	α = 0.760	**4**

Table 1. *Cont.*

Questionnaire and Scales Contained Therein	Cronbach's Alpha	Number of Items
Technology commitment (TB) *Likert scale: 1 = Strongly disagree to 5 = Strongly agree*		**12**
Scale: Acceptance of technology *Sample Item: I am very curious about new technical developments.*	α = 0.713	4
Scale: positive technology consequences *Sample Item: Whether I am successful in using contemporary technology depends primarily on myself.*	α = 0.607	4
Scale: negative technology consequences *Sample Item: When dealing with new technology, I am often afraid of failing.*	α = 0.676	4
Short Scale for Measuring General Self-efficacy Beliefs (ASKU) *Likert scale: 1 = Strongly disagree to 5 = Strongly agree* *Sample Item: In challenging situations, I can rely on my abilities.*	α = 0.615	**3**
Previous experience with AR applications (own items) *Likert scale: 1 = No experience at all to 10 = A lot of experience* *Sample Item: I have used AR applications practically (e.g., with applications on the tablet or laptop)*	α = 0.879	**3**
Attitude towards AR applications (own items) *Likert scale: 1 = Negative at all to 10 = Positive* *Sample Item: My general attitude towards AR applications*	α = 0.615	**3**
Subject-specific self-confidence (own items) *Likert scale: 1 = Strongly disagree to 5 = Strongly agree* *Sample Item: I have a clear idea of how proteins are structured.*	α = 0.777	**4**

[1] The original questionnaire contains a total of 18 items. [2] One item from the original scale was excluded from the scale during data analysis to improve reliability.

The *video recordings of the lesson* were edited, and the video and audio streams of the two stationary cameras and multiple HoloLens were synchronized and merged for easier analysis. For the analysis, a category system was developed (mainly deductive category development) and a structured content analysis in MAXQDA was conducted [36]. As the number of video recordings is limited, the analysis was carried out by two project team members in a consensus procedure.

The *interviews* varied in length from 12 to 27 min and were transcribed verbatim manually. A category system was developed (inductive-deductive category development) and a structured content analysis was conducted [36]. The category system comprises the following categories: motivation, interest, didactic setting, usability, other. Each category includes various sub-codes. As with the video recordings, MAXQDA was used for the content analysis. A total of 699 codes were assigned and allocated to the corresponding passages in the transcripts. Video analysis was carried out by two team members of the project in a consensus procedure due to the limited number of interviews.

The thematic focus of this paper is primarily on the contents and results of the paper-based survey. In addition, selected findings from the interviews are presented. Since the video analysis pursues other questions and is very extensive, these results will be published in a separate paper (paper in preparation).

3. Results

3.1. Attitude and Experience towards AR Technologies (RQ1)

The results of the paper-based survey show that students have a strongly positive attitude towards AR technologies. With a mean value of 8.04 on a scale of 1–10, the value of the corresponding scale "attitude towards AR applications" is high. However, the standard deviation of 1.25 shows that there were different opinions (N = 18, min = 5.00, max = 10.00). This finding is also confirmed by several students' statements in the interviews. As selected quotes from the interviews show (see below), some students were very positive about new technologies and AR applications, others were more critical. However, the statements also show that the students' attitudes changed positively in some cases (n = 8) as a result of participating in the teaching unit with HoloLens, where they were able to make their own experiences with an AR technology. As the interviews were conducted in German, the quotes were translated into English by the authors. The symbols (-) in the quotes indicate pauses in speech, with a dash indicating a pause of about one second.

> *S: I think it's more the idea of what's possible. In general, I find new technologies very exciting. Or now, with the whole virtual system, I find that exciting. But it's more something that you have a concrete idea of what's possible with it. And therefore, it has shown me what is possible and how it can be implemented, and therefore it has simply become more concrete. (Interview 09C, pos. 44)*

> *S: Yes, I am interested in new technologies in principle. But personally, I would never buy the latest iPhone or a new smartphone or a new computer, that's not so important to me. However, I think that for school, you should keep up with technology and always be a bit "up to date", so that if something is available that is really suitable, you can actually use it. (Interview 08C, pos. 50)*

> *S: Yes, well, (-) I think I'm a bit more open-minded, I'm always a bit more "it's cool, but I'm not really interested". Well, I bought a new mobile phone three months ago, but only because I had to, because my old one was screwed up. (laughter) Well, I always look at new products, but it's not that I think "oh my God, I need this". And I think now with that, I found it quite cool to put it [HoloLens] on, and I could imagine pursuing that (-) further. (Interview 08D, pos. 28–32)*

> *S: Well, I was always very, very skeptical about these VR glasses until now. Because I only knew them in the context of video games. And that would be taking it too far for me personally. I've never tried them myself in this context. And this is actually the first time I've seen it as a sensible application. And that is interesting, of course. So that would be something I would also be more in favour of. (Interview 08A, pos. 27)*

Although the students generally have a positive attitude towards AR technologies, the results of the paper-based survey show that they have had very little experience with it so far. On the scale of 1–10, the mean value in the corresponding scale "previous experience with AR applications" is 3.13, with 13 students having a value between 1 and 3 and only 5 students having a value above 3 (N = 18, SD = 1.92, min = 1.00, max = 7.33).

3.2. Relation of Attitude towards AR Applications to Current Motivation to Complete the AR-Supported Learning Task (RQ2)

We investigated the extent to which the students' attitudes are related to other student characteristics. Two statistically significant correlations were found. The attitude towards AR applications is positively correlated with the motivation to participate in the teaching unit with AR. This means that the more positive the attitude towards AR applications, the greater is the interest in the learning setting with AR (N = 18, r = 0.503, $p = 0.33$). According to Cohen [34], this is a strong effect. Furthermore, a negative, significant correlation exists between the attitude towards AR technologies and the scale "fear of failure" (N = 18, r = 0.506, $p = 0.032$): The higher the attitude towards AR applications, the lower the fear of failure in the teaching unit. This too is a strong effect.

3.3. Motivation to Engage with the Topic and the Technology and Its Relation to Student Characteristics (RQ3)

The students were very motivated to participate in the teaching unit, to engage with the teaching content, and to work with the new technology. This is quite understandable, as the students voluntarily decided to participate. In the corresponding scale "current motivation specific to the content of the study", the mean value is 8.7 with a maximum value of 10 (N = 18, SD = 0.89, min = 7.00, max = 10.00). The students were very motivated to work with HoloLens and thus with the technology that was new to them. The mean value for this item was 9.44, the highest out of the 4 items in this scale (N = 18, SD = 0.78, min = 8.00, max = 10.00). A total of 16 out of 18 students also explicitly stated in the interview that their motivation was high due to the new technology, as the following examples show.

> *S: No, I really wanted to see (-) what it looks like, what you can do with it and, because I really haven't worked with HoloLens yet and that's why I really wanted to see (-) what it's like and what you can do with it in science. (Interview 08D, pos. 10)*

> *S: Um, [my motivation was] actually very high, because I have never worked with such a HoloLens. And especially in the area of molecules, I remember from my school days that we only had it (-) on paper in 2D and (-) it's just something else when you can look at it (-) in 3D. (Interview 09D, pos. 8)*

Although the students were already highly motivated before the teaching unit, 12 students explicitly stated in the subsequent interviews that their motivation further increased during the AR teaching unit, as can be seen from the following example:

> *S: Yes, it [my motivation] has certainly always remained high and it has definitely exceeded expectations. And therefore, the motivation has increased even more, if at all possible, because you can see so many possibilities from the project itself, and how you can implement it at school. And therefore, I was totally enthusiastic about the whole project. (Interview 09C, pos. 32)*

For the scale "current motivation specific to the content of the study", several correlations with other areas could be identified. The higher the motivation, the greater is the interest in the learning setting with AR (N = 18, r = 0.629, p = 0.005). According to Cohen [34], this is a strong effect. The current motivation also correlates statistically significantly with the scale "probability of success". This means that the higher one's own motivation, the higher one estimates the probability of success (N = 18, r = 0.484, p = 0.042). This is a medium effect. Finally, there is a highly significant correlation between motivation and subject-specific self-confidence (N = 18, r = 0.759, p = 0.000). The greater the motivation for the participation in the teaching unit, the higher the professional self-confidence regarding the topic of the teaching unit. This is also a strong effect.

3.4. Level of Student Commitment to Technology and Its Relation to Other Student Characteristics (RQ4)

From the results of the questionnaire technology commitment (TB) it is evident that the students are strongly convinced that they can handle technologies with competence. The mean value for the scale "negative technology consequences" is 1.78 (N = 18, SD = 0.59, min = 1.00, max = 3.25) on a Likert scale of 1–5. This scale is negatively poled, and the low value indicates that students hardly fear negative consequences when using technologies. The other two scales of the questionnaire TB were also answered positively by the majority of the students, whereby the scale "positive technology consequences" with a mean value of 3.92 (N = 18, SD = 0.65, min = 3.00, max = 5.00) was answered slightly more positively than the scale "acceptance of technology" with a mean value of 3.54 (N = 18, SD = 0.73, min = 2.00, max = 5.00).

For the scale "negative technology consequences" in this questionnaire there is a statistically significant difference between the perception of the female students (n = 7) and the male students (n = 11) (Mann-Whitney-U-Test exact, U = 15.50, d = 1.127, p = 0.035). Accordingly, female students (M = 2.14, SD = 0.63, min = 1.25, max = 3.25) are much more likely to fear negative consequences when using technology than male students (M = 1.55, SD = 0.46, min = 1.00, max = 2.50). According to Cohen [34], this is a very strong effect. This is the only statistically significant difference that could be found regarding the factor gender.

There is a significant, negative correlation between the scale "negative technology consequences" and the scale "acceptance of technology" (N = 18, r = −0.585, p = 0.11). This means that the less anxious and overwhelmed students feel with new technology, the greater is their curiosity and liking of technical devices. This is a strong effect. Furthermore, the scale "negative technology consequences" and the "current motivation specific to the content of the study" correlate negatively and significantly with each other (N = 18, r = −0.490, p = 0.039). The less anxious and overwhelmed students feel about new technology, the greater is their motivation to participate in the teaching unit. This is a medium effect. Finally, there is also a positive, significant correlation between the scale "positive technology consequences" and the students' "attitude towards AR applications" (N = 18, r = 0.648, p = 0.004). Thus, the more one estimates the effects of the technology to be positive, the more positive is one's attitude towards AR applications. This is a strong effect.

The following table (Table 2) shows the statistical values of the correlations calculated for each of the scales. Only the statistically significant correlations were reported in Section 3.

Table 2. Overview of the correlations of the individual scales used in the paper-based survey.

		QCM: Interest	**QCM: Probability of Success**	**QCM: Fear of Failure**	**TB: Acceptance of Technology**	**TB: Negative Technology Consequences**	**TB: Positive Technology Consequences**	**Previsou Experience with AR Apllications**	**Attitude towards AR Apllications**	**ASKU: Short Scale for Measuring General Self-Efficacy Beliefs**	**QCM: Challenge**	**Subject-Specific Self-Confidence**
QCM: Probability of success	Pearson correlation coefficient	0.275										
	significance (two-sided)	0.269										
	N	18										
QCM: Fear of failure	Pearson correlation coefficient	−0.152	−0.581 *									
	significance (two-sided)	0.546	0.011									
	N	18	18									
TB: Acceptance of technology	Pearson correlation coefficient	0.205	0.206	−0.218								
	significance (two-sided)	0.414	0.412	0.385								
	N	18	18	18								
TB: Negative technology consequences	Pearson correlation coefficient	−0.332	−0.136	0.431	−0.585 *							
	significance (two-sided)	0.178	0.592	0.074	0.011							
	N	18	18	18	18							
TB: Positive technology consequences	Pearson correlation coefficient	0.297	0.106	−0.366	−0.054	−0.345						
	significance (two-sided)	0.232	0.677	0.135	0.832	0.161						
	N	18	18	18	18	18						
Previous experience with AR applications	Pearson correlation coefficient	0.219	−0.284	0.22	0.027	0.285	−0.312					
	significance (two-sided)	0.382	0.254	0.381	0.914	0.251	0.208					
	N	18	18	18	18	18	18					
Attitude towards AR applications	Pearson correlation coefficient	0.503 *	0.348	−0.506 *	0.132	−0.346	0.648 **	−0.062				
	significance (two-sided)	0.033	0.157	0.032	0.601	0.16	0.004	0.806				
	N	18	18	18	18	18	18	18				

Table 2. *Cont.*

		QCM: Interest	QCM: Probability of Success	QCM: Fear of Failure	TB: Acceptance of Technology	TB: Negative Technology Consequences	TB: Positive Technology Consequences	Previsou Experience with AR Applications	Attitude towards AR Applications	ASKU: Short Scale for Measuring General Self-Efficacy Beliefs	QCM: Challenge	Subject-Specific Self-Confidence
ASKU: Short Scale for Measuring General Self-efficacy Beliefs	Pearson correlation coefficient	0.29	0.047	−0.04	0.091	−0.216	−0.079	0.064	0.086			
	significance (two-sided)	0.244	0.852	0.876	0.72	0.389	0.756	0.801	0.733			
	N	18	18	18	18	18	18	18	18			
QCM: Challenge	Pearson correlation coefficient	−0.091	−0.213	−0.157	0.255	−0.364	0.306	−0.156	0.383	−0.255		
	significance (two-sided)	0.719	0.397	0.533	0.307	0.138	0.217	0.536	0.117	0.308		
	N	18	18	18	18	18	18	18	18	18		
Subject-specific self-confidence	Pearson correlation coefficient	0.428	0.281	−0.315	0.059	−0.211	−0.133	0.339	0.119	−0.012	0	
	significance (two-sided)	0.076	0.258	0.202	0.816	0.4	0.599	0.169	0.639	0.963	10	
	N	18	18	18	18	18	18	18	18	18	18	
Current motivation specific to the content of the study	Pearson correlation coefficient	0.629 **	0.484 *	−0.401	0.325	−0.490 *	0.04	0.106	0.192	0.263	0.004	0.759 **
	significance (two-sided)	0.005	0.042	0.099	0.188	0.039	0.875	0.675	0.444	0.291	0.987	0
	N	18	18	18	18	18	18	18	18	18	18	18

* Correlation is significant at the 0.05 level (two-sided). ** Correlation is significant at the 0.01 level (two-sided).

4. Discussion

Educational researchers and policy makers in many countries have started initiatives in recent years to improve the quality and efficiency of teaching and learning. These initiatives are motivated by the realization that the use of static textbooks and the traditional chalk and talk teaching method do not sufficiently engage students and that learning outcomes are lower as a result of this [23]. Indeed, it is assumed that the educational conditions of so-called millennials lead to unique thinking patterns, and consequently their brain structures physically change. For this reason, they can easily become bored when they encounter traditional teaching methods [27]. In recent years, research and development in the field of technology enhanced learning has therefore increasingly focused on emerging technologies such as mobile learning, serious games and both virtual and augmented reality in order to adapt learning environments to the needs of learners and thus support learning processes more effectively [20]. In various studies, augmented reality in particular is seen as having many possibilities and advantages for supporting learning, and this technology is consistently acknowledged as having enormous potential [22,37,38].

The results of the study presented here show that the students were very motivated to work with the technology. However, they had little experience with AR applications at the time of the survey. This result is rather surprising, as the students in question all belong to the millennial generation. In the literature, they are characterized by having grown up with technology and frequently using technical devices [27]. For this reason, it could have been expected that the students would already have had more experience with AR applications. It is also assumed that millennials use digital technologies in a sophisticated way, that they have no problems using complex technologies, and that they are comfortable with multi-tasking [27]. The familiarity with technologies that millennials are generally attributed with is reflected in this study by the fact that the students are convinced that they can competently deal with technologies. However, according to the results, there is a significant difference in this regard between female and male students. Female students are much more likely to fear negative consequences when using technology than male students. This is an important finding in relation to the use of technology in learning environments, as fears of this kind can have a negative impact on the learning process. In this respect, it is very important to know and take into account the learners' individual preconditions [25] and to carefully support female learners in particular.

Since the students already had a positive attitude towards the technology before they worked with it, most of them did not experience a significant change in their attitude. However, according to their statements in the interviews, the attitude of eight students has changed positively as a result of working with HoloLens. The same effect was found for the motivation of the students. Although motivation was already very high, 12 students explicitly stated in the interview that their motivation had increased even more based on participating in the AR teaching unit. This result goes hand in hand with findings from other studies. Besides learning gains, the most commonly reported benefit of AR in learning environments is the positive impact on learners' motivation [13].

In the study ALex, the attitudes and motivational aspects of students were further explored. It was found that attitudes towards AR technologies, as well as towards new technologies in general, are related to motivational factors and aspects of self-efficacy in the context of the AR-supported teaching unit. It therefore seems significant that we acknowledge that AR is a technology that is still largely unknown, even among young people. If learners are not confident in using this technology, or are not motivated to engage with it, this can have an impact on the learning process and the learning outcome. Technological skills as well as corresponding motivational or affective preconditions are not simply inherently provided due to generational characteristics [39].

Previous work has already pointed out that there is still little practical experience with AR in classroom settings [8] and there is limited reliable knowledge about the design of learning opportunities with AR technologies. Thus, it is widely unclear how AR can be integrated into the classroom in a didactically meaningful way, and it is so far mostly unknown which aspects should be taken into account when designing AR teaching units [15]. At the same time, there is hardly any knowledge about learners' attitudes towards AR technologies and how they interact and learn with them. Although AR technologies are generally seen as having great potential for educational purposes, there are indications that not all learners can benefit from them to the same extent. For example, it was shown that while medium and low achieving learners gained learning outcomes with AR, high achieving learners gained better learning outcomes in traditional teaching without the use of AR [18]. Likewise, the results of ALex show that learners have different attitudes towards AR technologies and have had different experiences in the AR-supported teaching unit. As has been stated before, such individual learning preconditions and student characteristics can influence the learning outcome.

When using AR applications in learning environments, teachers should therefore address and take into account the individual preconditions and characteristics of individual learners. A successful AR application in education depends not only on the technical aspects, but also on the pedagogical characteristics of the context in which it is used [5]. Here, the characteristics of the supply are important, but so are those of use (both of which moderate and determine the learning outcomes (see Figure 1)).

The aim of ALex was to provide more information about students' characteristics and individual learning preconditions in relation to learning with AR technologies. The results provide preliminary but valuable insights that may be important for the use of AR applications in educational settings as well as for further research projects. So far, there have hardly been any studies which address the usefulness of AR from a psychological perspective [40] or deal with the learners' preconditions for successfully engaging with AR technologies, as examined in ALex. Researchers need to better understand how specific content can be delivered and in what ways AR technologies can support this while considering the abilities and limitations of learners of varying ages and abilities [40]. In addition, future research should investigate the impact of integrating different pedagogical approaches into AR interventions. There are still major research gaps in this regard, as there are hardly any studies so far that have included pedagogical concepts as a research variable or have presented results on the pedagogical approaches that have been implemented in AR interventions [15]. If AR technologies are to be used more widely and successfully for educational purposes in the future, these concerns must be clarified and taken into account.

With ALex, we intended to make a contribution to this and indicate that learners should be given more attention in the future, both in the design of pedagogical concepts and in research studies. However, this is an exploratory study with a limited number of participants. Moreover, the students participated in the study voluntarily. The study therefore has several limitations. For future research projects, it would be very desirable to include a larger group of students in the study. It would also be very interesting to work with all learners of a certain group or course, so that not only students with a specific interest in the project voluntarily participate. Furthermore, studies that extend over a longer period of time are needed in order to be able to explore the long-term effects. Most interventions with AR in education are relatively short-term. In the meta-analysis by Garzón, Kinshuk, Baldiris, Gutiérrez, and Pavón [15], 93% of interventions lasted less than one month. Likewise, in our study, learners were only surveyed before and after a single AR-supported teaching unit. In general, it has to be noted that studies related to AR in education are still immature compared to studies on other technologies in this field [13]. Although the findings so far on the possibilities and unique potential of AR are very promising, further studies and research projects are needed to successfully and sustainably integrate the technology into teaching and learning processes in the future.

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Appendix A

Table A1. Overview of the questionnaires used in the paper-based survey.

Questionnaire and Scales Contained Therein	Number of Items
Questionnaire on Current Motivation (QCM) *Likert scale: 1 = Disagree to 7 = Agree*	**18**
1. I like riddles and puzzles. (I)	
2. I think I am up to the difficulty of this task. (P)	
3. I probably won't manage to do this task. (P−)	
4. While doing this task I will enjoy playing the role of a scientist who is discovering relationships between things. (I)	
5. I feel under pressure to do this task well. (A)	

Table A1. *Cont.*

6. This task is a real challenge for me. (C) 7. After having read the instruction, the task seems to be very interesting to me. (I) 8. I am eager to see how I will perform in the task. (C) 9. I'm afraid I will make a fool out of myself. (A) 10. I'm really going to try as hard as I can on this task. (C) 11. For tasks like this I don't need a reward, they are lots of fun anyhow. (I) 12. It would be embarrassing to fail at this task. (A) 13. I think everyone could do well on this task. (P) 14. I think I won't do well at the task. (P−) 15. If I can do this task, I will feel proud of myself. (C) 16. When I think about the task, I feel somewhat concerned. (A) 17. I would work on this task even in my free time. (I) 18. I feel petrified by the demands of this task. (A) (C): Challenge (I): Interest (Items have to be adapted to the task) (P): Probability of success (A): Anxiety (This scale has been translated as "fear of failure" by the authors of this paper.) Vollmeyer, R.; Rheinberg, F. Motivational Effects on Self-Regulated Learning with Different Tasks. *Educ Psychol Rev* **2006**, *18*, 239–253, doi:10.1007/s10648-006-9017-0. *The original questionnaire in German is available at:* *Rheinberg, F.; Vollmeyer, R.; Burns, B.D. FAM: Ein Fragebogen Zur Erfassung Aktueller Motivation in Lern- Und Leistungssituationen. Diagnostica 2001, 47, 57–66, doi:10.1026//0012-1924.47.2.57.*	
Current motivation specific to the content of the study (own items) *Likert scale: 1 = Not motivated at all to 10 = Very motivated* Please indicate on a scale of 1–10 how motivated you are . . . 1. . . . to participate in this teaching unit. 2. . . . to work with HoloLens. 3. . . . to engage with the content of the teaching unit "molecules". 4. . . . to engage with models in the subject science and technology.	**4**
Technology commitment (TB) *Likert scale: 1 = Strongly disagree to 5 = Strongly agree* 1. I am very curious about new technical developments. (TA) 2. I easily take a liking to new technical developments. (TA) 3. I am always interested in using the latest technical devices. (TA) 4. If I had the opportunity, I would use technical products even more often than I do now. (TA) 5. When dealing with new technology, I am often afraid of failing. (TC−) 6. Dealing with technical innovations is usually too demanding for me. (TC−) 7. I am afraid of breaking new technical devices rather than using them properly. (TC−) 8. I struggle with new technology—I just can't do it most of the time. (TC−) 9. Whether I am successful in using contemporary technology depends primarily on myself. (TCC) 10. It is up to me whether I succeed in using new technical developments - this has little to do with chance or luck. (TCC) 11. If I have problems in dealing with technology, it is basically up to me to solve them. (TCC) 12. What happens when I deal with new technical devices is entirely under my control. (TCC) (TA): Technology acceptance (TC): Technology competence (TCC): Technology control convictions *All scale names and questions have been translated into English by the authors. The original questionnaire in German is available at:* *Neyer, F.J.; Felber, J.; Gebhardt, C. Entwicklung und Validierung einer Kurzskala zur Erfassung von Technikbereitschaft. Diagnostica 2012, 58, 87–99, doi:10.1026/0012-1924/a000067.*	**12**

Table A1. *Cont.*

Short Scale for Measuring General Self-efficacy Beliefs (ASKU) *Likert scale: 1 = Strongly disagree to 5 = Strongly agree* 1. In challenging situations, I can rely on my abilities. 2. I can handle most of the problems well on my own. 3. Even demanding and complex tasks I can usually solve well. *All questions have been translated into English by the authors. The original questionnaire in German is available at: Beierlein, C.; Kovaleva, A.; Kemper, C.J.; Rammstedt, B. Ein Messinstrument zur Erfassung subjektiver Kompetenzerwartungen. GESIS—Leibniz-Inst. Für Sozialwissenschaften 2012, 1–24.*	**3**
Previous experience with AR applications (own items) *Likert scale: 1 = No experience at all to 10 = A lot of experience* 1. My experience with AR applications to date in general. 2. I have dealt with AR applications theoretically (e.g., reading journal articles). 3. I have used AR applications practically (e.g., with applications on the tablet or laptop)	**3**
Attitude towards AR applications (own items) *Likert scale: 1 = Negative at all to 10 = Positive* 1. My general attitude towards AR applications. 2. My attitude towards AR applications in relation to their use in teaching and learning scenarios in the university. 3. My attitude towards AR applications in relation to their use in teaching and learning scenarios at secondary school level.	**3**
Subject-specific self-confidence (own items) *Likert scale: 1 = Strongly disagree to 5 = Strongly agree* 1. If I had to explain to someone on a chemical level what proteins are, I could do that. 2. If I had to explain to someone on a chemical level what amino acids are, I could do that. 3. I have a clear idea of how proteins are structured. 4. I have an understanding that proteins have different forms and why that is.	**4**

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