Show Me the Universe! Perceived Usability and Task Load of an AR Mobile-App in Secondary School Learning

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Abstract. Modern digital artefacts not only affect the way we work but increasingly also the way we learn and teach. The Internet, smart devices, as well as innovative forms of human-content interaction open up new pathways for successful knowledge transfer. The work presented in this paper aims to explore one of these recent developments, i.e. the use of Augmented Reality in school learning. We report on an experimental study in which two cohorts of secondary school students used a smartphone-based AR mobile-app to learn about astronomy and the solar system. The goal of the experiment was to evaluate the app's perceived usability and task load associated with a set of particular learning exercises. Results point to an average perceived usability and moderate task load, independent of the students' gender. Further, we found a negative correlation between the perceived usability and task load, even though this was only significant for male students.

Keywords: Technology-supported teaching · Augmented Reality · Technology acceptance · System Usability Scale · NASA-TLX

1 Introduction

Digitization efforts in teaching can significantly affect students' learning processes as well as teachers' didactic concepts. In particular, opportunities related to interactive simulations and educational games have expanded the limits of knowledge transfer [34]. However, it is often still necessary to convince teachers

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of the effectiveness of these types of digital learning environments and consequently support their integration into the classroom. One of these rather progressive technologies to be used in teaching is Augmented Reality (AR). To this end, the fact that nowadays many children already own and use smartphones may be considered a supportive factor as these devices can act as low-cost platforms for AR content. The presented research aims to measure the perceived usability and task-load of a smartphone-based AR learning application with children at the secondary school level.

2 Background, Related Work and Theoretical Foundation

AR applications, similar to their Virtual Reality (VR) siblings, have been around for more than two decades [37]. Although the two technologies are often associated with each other as they serve comparable areas, they do pursue different goals and have different technological requirements.

2.1 Virtual vs. Augmented Reality

While VR refers to computer-generated 3-dimensional environments in which users can move and interact freely, AR extends the real world with virtual objects. A VR environment is thus an environment in which users completely immerse themselves in a synthetic world, in which the physical laws of gravity, material properties, and time may no longer apply. On the contrary, AR uses the real world as a base, which is consequently also a limiting factor. As such, the two technologies may be put on the two opposite ends of what Miligram and colleagues consider the Reality-Virtuality (RV) Continuum [28] (cf. Fig. 1).

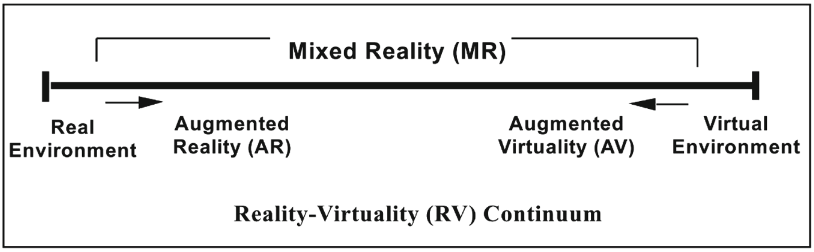

Fig. 1. Reality-Virtuality (RV) Continuum according to Miligram et al. [28, p. 283].

Here, the left end of the continuum defines the real environment, which consists exclusively of real objects; i.e. anything that can be observed directly or through a window or (video) display. On the opposite side are virtual environments, which consist exclusively of virtual objects. These include, for example, computer graphic simulations or interactive VR video games. Everything that is within these two end-points is referred to as a mixed reality (MR) environment and is usually roughly assigned to one of the two extremes.

Work in the VR/AR field started in the 1960s with Sutherland's 'The Ultimate Display', which was based on the argument that computer technology had already advanced so far that it would soon be possible to give people information, objects, or reactions that were not, as in the real world, bound to physical or mathematical laws [38]. Thus, initial research focused on the development of virtual 3D worlds (i.e., VR). Only years later, the supplementation of real world settings through virtual objects, i.e. AR, became a relevant topic [7]. Although the basic idea of AR was to include mobility, it was only with 'The Columbia Touring Machine' by Feiner and colleagues that the first mobile augmented reality system (MARS) was developed [18].

2.2 Application Areas for AR

Thanks to the increasing proliferation of smart devices (i.e., smartphones and tablets), recent years have seen a number of relevant application areas for AR. In highly individualized, just-in-time/just-in-sequence manual manufacturing settings, for example, assembly line workers may be trained through head-mounted displays (HMD) providing contextualized visual information [11]. AR technology has also found its place in marketing. Pepsi, for example, had an AR camera installed at a London bus stop. There, one could see tigers strolling down the street, UFOs racing towards the bus stop, or huge tentacles protruding from the sewer. These and similar AR 'prankvertisements' aim to create viral campaigns through provocative events, offering viewers an entertainment value, and consequently promoting the exchange of social media content [35].

Medicine is another field of application where AR technology may provide a significant contribution. The greatest medical advances in recent decades have been diagnostic imaging, ultrasonography, mammography, computed tomography (CT), etc. All the visual data connected to these procedures is still displayed on 2D flat screens and thus forces doctors to shift their viewpoints during surgery. It is thus not surprising that the medical industry sees great potential in AR[1]. To name a specific example, Philips introduced in 2017 a new type of navigation technology for mini-invasive interventions on the spine, where, through an optical tracking system, information from a patient and live images of the body are delivered to the screen in the operating room; thus, showing the surgeon exactly where to start so as to achieve a positive result[2].

Furthermore, AR is being used to support navigation tasks. That is, environments are no longer depicted as two-dimensional maps, but rather augmented via arrows mapped onto reality through the camera of the smartphone, indicating directions, street names, and other points of interests. This idea of perceiving

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[1] Online: https://hbr.org/2018/03/how-augmented-reality-will-make-surgery-safer [accessed: January 15^{th} 2020].

[2] Online: https://medialist.info/2017/01/13/ar-healthcare-augmented-reality-in-der-medizin/ [accessed: January 15^{th} 2020].

graphical information has also been used by the automotive industry, where navigational information, current speed, or fuel usage are increasingly embedded into car windshields or other types of head-up displays [29]. Finally, AR has seen an uptake in the tourism industry, where it supports destination management [17], in the real estate sector, where it helps to convey future living experiences [43], as well as in learning contexts.

2.3 AR in Learning Contexts

AR fundamentally changes the way learning content is taught, for which it has also received much attention in past research [3]. Using web-enabled devices such as smartphones or tablets, AR programs can provide students with location-specific information at exactly the right time and seamlessly embed data (via image or object markers) in the real context [9]. It has great educational potential because it has the ability to merge virtual and real worlds and thus offers new opportunities to improve both learning and teaching quality [31]. For example, intelligent learning books and learning cards already contain markers, which, when scanned by an AR system, generate additional data for learners [1]. Here, the most prominent examples focus on learning topics such as history, art, technology, biology, or astronomy, where the physical environment is enriched through AR artifacts [36]. AR seems particularly effective for activities in which students learn things that cannot be seen in the real world or without a specific device [12]. Furthermore, it has repeatedly proven to be motivating [8,13,14,39] and to positively influence students' learning outcomes [4,23,26,27].

While this clearly highlights the potential AR technology offers in learning contexts, it is often the low acceptance of end users (both teachers as well as students) which hampers widespread adoption and thus asks for additional studies to gain a better understanding of people's needs and expectations [30]. To this end, influences and consequent challenges of accepting all kinds of technologies in various settings and contexts have been studied for more than two decades (e.g., [19,21,25,33]).

2.4 Technology Acceptance

Next to diffusion and adoption research, which explores factors that influence the adoption and use of innovative systems, it is mainly the body of literature on acceptance which aims at offering explanations as to why an individual decides to use an existing technology. To this end, previous work is predominantly rooted in information systems research, where the integration of technology is perceived a challenge of both product adoption and respective organizational change (e.g. [6,32,44]).

Numerous models aim to measure the acceptance of information technology-based systems. However, the Technology Acceptance Model (TAM) developed by Davis and colleagues [15,16] is still considered the most influential and widely used framework [24]. It is based on the Theory of Reasoned Action (TRA) [2], which assumes that the user's attitude towards a system is a decisive factor for its use. Building on this, the acceptance of technology is determined by two main variables; i.e. its Perceived Usefulness (PU) and its Perceived Ease of Use (PEOU). PU is defined as *"the prospective user's subjective probability that using a specific application system will increase his or her job performance within an organizational context"* [16, p. 985]. Yet, while a potential user might deem a particular application system useful, its actual usage may be inhibited by additional efforts caused through difficult or non-intuitive operation procedures. Therefore, Davis defines the PEOU of a system as *"the degree to which a person believes that using a particular system would be free of effort"* [16, p. 985]. Since then, both PU (i.e., TAM2) [42] and PEOU [40] underwent further investigation, leading to a more comprehensive and integrated framework referred to as TAM3 [41].

Coming back to a better understanding of the use and acceptance of AR technology in learning settings, the focus of our initial piece of research was on secondary school students and their perceived ease of using a smartphone-based AR mobile-app. More precisely, we solely investigated the PEOU construct of the TAM framework. To this end, we were particularly interested in students' perceived usability and perceived task load when using the app to learn about astronomy.

3 Methodology

As of 2018, the regulation on digital education of the Austrian Federal Ministry of Education, Science and Research obliges Austrian schools to develop the digital competences of their students. As such, the regulation aims to provide students with the ability to select and use suitable (digital) tools and methods for specific learning scenarios in both school and private contexts. To explore the use of smartphone based AR technology, we conducted a learning experiment with two cohorts of 3rd year students in a secondary school. Preceding the study, we obtained relevant approval from the local education authorities, the head of school, and the students' parents and guardians. Furthermore, our institution's research ethics group cleared the study set-up and utilized materials.

3.1 Experimental Procedure

The experiment focused on the solar system and respective physical phenomena. First, students were informed about AR and the devices they could use it with. Next, the class teacher, who was present throughout the entire experiment, divided all students into groups, instructed them to download the *Areeka*[3] app to their phones or, if necessary, to tablets provided by the school. Subsequently, students received a task sheet, an accompanying booklet, and written instructions on how to use the app and the booklet alongside their standard textbook. Through markers, which were found after each section in the booklet, artifacts and additional information could be visualized on the smartphone or

[3] https://areeka.net/en/.

tablet. Next, students were given 30 min to learn about the solar system, moon phases, as well as lunar and solar eclipses. Students worked individually with hardly any interference by us or the school teacher. Finally, after the worksheets were completed, students were asked to complete a questionnaire investigating perceived usability of the AR mobile-app and perceived task load.

3.2 The Questionnaire

In order to measure perceived usability and task load, we used the System Usability Scale (SUS) [10,22] and the NASA Task Load Index (NASA-TLX) [20]. The SUS is based on 10 questions (alternating between positive and negative usability statements) aiming to measure the subjectively perceived usability of interacting with a system on a 5- or, as in our case, 7-point Likert scale (1 = *strongly disagree*; 7 = *strongly agree*). Answers were then converted to a score (0–100), where previous industry comparisons have shown that average system usability would lie between 60 and 80 [5].

As for the task load, the NASA-TLX questionnaire computes a task load score based on a person's perceived mental, physical, and temporal demand, performance, effort, and frustration when completing a task. Here, we also used a 7-point Likert scale (1 = *very low*; 7 = *very high*). In order to rank the relevance of these sub-scales for a given task, the NASA-TLX recommends pair-wise comparison to generate an order and respective multiplication factor. Perceived scores should then be multiplied by these factors and subsequently divided by 15 (i.e., the sum of distributed scoring points) to generate a weighted score. For our experiment, we asked an experienced secondary school teacher to compare the different sub-scales and generate such ratings, leading to the following multiplication factors: mental demand = 4; physical demand = 0 (note: the teacher did not see any physical demand associated with the given task); temporal demand = 3; performance = 3; effort = 2; frustration = 3;

Finally, the last part of the questionnaire collected demographic data on the children's age and gender. With respect to the analysis, we then derived the following hypotheses as guidance:

- H1: There is a difference in the perceived usability (SUS) of the AR mobile-app between male and female participants.
- H2: There is a difference in the weighted perceived task load (NASA-TLX) operating the AR mobile-app between male and female participants.
- H3: There is a negative correlation between the perceived usability (SUS) and the weighted perceived task load (NASA-TLX) operating the AR mobile-app.

4 Results

A total of n = 49 students (28 female) from two 3$^{\text{rd}}$ year secondary school classes took part in this study. Their age ranged from 12 to 14 years with the majority (67%) being 13 years old. With respect to perceived usability, students evaluated the app with an average SUS score of 71.47 ($SD = 16.82$), which points to an overall acceptable intuitiveness of the app. The difference between perceived usability with female ($Mean = 73.90$; $SD = 13.79$) and male ($Mean = 68.23$; $SD = 20.08$) students was not significant, for which H1 had to be rejected (cf. Table 1 and Fig. 2).

Table 1. System usability scale

SUS	Male	Female	Total
Average	68.23	73.90	71.47
Standard deviation	20.08	13.79	16.82
Confidence interval 95%	[59.09, 77.37]	[68.55, 79.24]	[66.64, 71.47]

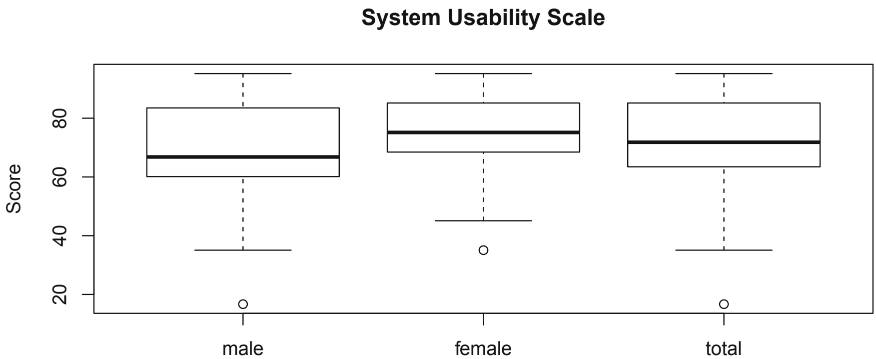

Fig. 2. System usability scale

Looking at the perceived task load, students evaluated the interaction with the app to be moderately demanding, expressed by an overall weighted NASA-TLX score of 3.34 ($SD = 0.76$). Again, the difference between genders was not significant ($female : Mean = 3.38$; $SD = 0.76 \mid male : Mean = 3.29$; $SD = 0.76$), for which H2 had to be rejected as well (cf. Table 2 and Fig. 3).

Finally, investigating a potential connection between perceived usability and weighted perceived task load, a Pearson correlation highlighted a significant negative relationship ($r = -0.33$; $p = 0.019$). This, however, seems to be gender-dependent, as the data shows a very weak and not significant correlation with female students ($r = -0.08$; $p = 0.080$), whereas the correlation with male students is strong and highly significant ($r = -0.61$; $p = 0.003$) (cf.Table 3). Thus, H3 may only be partly supported.

Table 2. NASA task load index

NASA-TLX	Male	Female	Total
Average	3.29	3.38	3.34
Standard deviation	0.76	0.76	0.76
Confidence interval 95%	[2.94, 3.63]	[3.08, 3.67]	[3.12, 3.55]

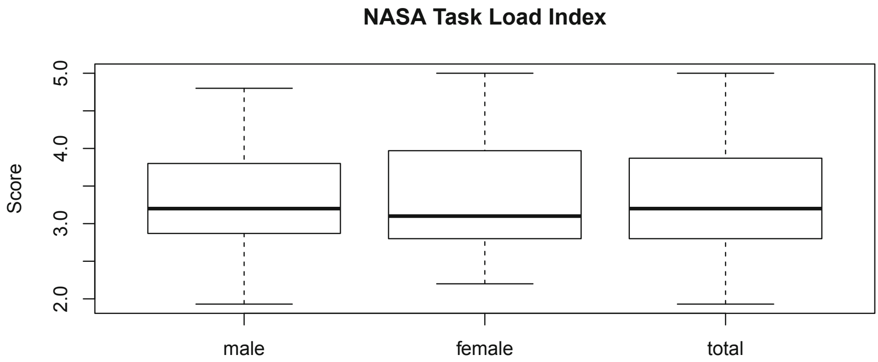

Fig. 3. NASA task load index

Table 3. Pearson correlation between SUS and NASA-TLX.

Correlation	Male	Female	Total
Coefficient r(47)	−0.61	−0.08	−0.33
Significance level p	0.003	0.080	0.019

5 Conclusion and Potential Future Work

Previous research has pointed to various challenges when using AR technology in learning settings [8]. The goal of the above presented study was thus to investigate secondary school students' perceptions on usability and task load when using a smartphone based AR mobile-app to learn about astronomy. In doing so, we focused on the overall perceived ease of use as one of the two determinants for technology acceptance put forward by Davis [16].

Our results have shown that students, regardless of their gender, perceive the app to be intuitive and its use for study tasks to be moderately demanding. Hence, it seems that at least from a student's point of view, one important threshold for AR acceptance in learning settings is met.

However, we also found a gender-dependent negative correlation between perceived usability and task load. That is, male students rated the perceived usability of the app lower when they perceived the overall task effort to be higher. While this may seem justified, we did not find this significant connection with female students, which may be an interesting direction for future research.

Other fields for further investigation may include aspects of perceived usefulness (i.e., the second important determinant for technology acceptance), the effects of AR usage on students' motivation, or potential effects on learning success.

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