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Augmented Reality in Education: Three Unique Characteristics from a User's Perspective

Jule M. KRÜGER[a*], Alexander BUCHHOLZ[a] & Daniel BODEMER[a]
[a]*Media-based Knowledge Construction, University of Duisburg-Essen, Germany*
*jule.krueger@uni-due.de

Abstract: In this paper, three technological characteristics of augmented reality (AR) are reframed from a perceptual, user's perspective and discussed concerning their potential for education and in the context of research on technology-supported learning. The first characteristic, *contextuality*, describes that users of AR can experience the real world and virtual elements simultaneously. The second characteristic, *interactivity*, includes the possibilities to interact with AR through the manipulation of both real objects and virtual properties, which offers novel possibilities for interaction. The third characteristic, *spatiality*, focusses on the linking of virtual objects to specific points in space and the more realistic three-dimensionality that AR visualizations offer. It is proposed that these three characteristics can provide a way to structure the broad research landscape of AR in education and form a basis for future research projects. Two studies are presented and linked to the three characteristics. In the first study, the comparison of a desktop simulation and an AR simulation in an individual learning setting is linked to the characteristics of interactivity and spatiality. In the second study, the contextuality of AR is systematically varied and exploited to present group awareness information about other learners next to these learners instead of separated from them. The results of the studies are discussed in the context of the three characteristics and the paper concludes that there are a lot of different educational settings in which AR could be beneficial. The classification of and systematic variation in research based on the three characteristics may form a basis to systematize educational AR research. Furthermore, the results of this research and the three characteristics themselves can inform the design of AR applications to support learning.

Keywords: Augmented reality, Contextuality, Interactivity, Spatiality, Technology-supported education, Multimedia learning

1. Introduction and background

During the past centuries, augmented reality (AR) has turned from a technological vision of the future, which could often be found in science fiction movies, to a technological achievement of the present, which can now be created by the smart technological devices we have in our pockets. This development concerning the access to the necessary technology creates novel opportunities for applying AR in different fields. One area that many recent studies concerning AR focus on is education (Cipresso, Giglioli, Raya, & Riva, 2018). Education may also be one of the most promising areas for applying AR and there is an increasing number of studies that focus on the opportunities that AR as a way of visualizing information has to offer for both individual and collaborative learning settings (Akçayır & Akçayır, 2017; Phon, Ali, & Halim, 2014; Radu, 2014; Wu, Lee, Chang, & Liang, 2013). In most of these studies, advantages of AR in comparison to more traditional learning settings are examined. Positive effects that have been found when using AR in education are enhanced learning performance and motivation, higher enjoyment and engagement, more positive attitudes towards the learning material, and a better collaboration between learners (Akçayır & Akçayır, 2017; Bower, Howe, McCredie, Robinson, & Grover, 2014; Chen, Liu, Cheng, & Huang, 2017; Dunleavy & Dede, 2014; Phon et al., 2014; Radu, 2014; Saidin, Halim, & Yahaya, 2015; Wu et al., 2013). Challenges that were discovered are for example technical limitations, the use of the application being too complicated and mentally overloading, the amount of time that has to be invested to develop the applications, and pedagogical issues when trying to integrate AR into the classroom (Akçayır & Akçayır, 2017; Bower et al., 2014; Dunleavy & Dede, 2014; Radu, 2014).

Over the years, various definitions of AR have been used in different areas of research. A rather general definition describes AR as "technology which overlays virtual objects (augmented components) into the real world" (Akçayır & Akçayır, 2017, p. 1) and in earlier definitions, AR is often linked to head-mounted displays, which were the preferred display devices before smartphones and tablets were available (Azuma, 1997). One of the most commonly used definitions by Azuma (1997) defines AR as systems with three characteristics: (1) combination of the real world and virtual elements, (2) real-time interactivity, and (3) registration in 3D. The definition is used in papers by Azuma (1997) and Azuma et al. (2001), which are the two most cited papers in AR as of 2016 (Cipresso et al., 2018). This underlines the importance of this definition and those three characteristics in AR research. In the current paper, Azuma's definition is employed because of its use in the educational field (e.g., Bower et al., 2014; Radu, 2014), its scope (not too broad or too narrow), and its independence of a technological device.

In addition to different definitions, there have also been various attempts to classify AR applications and technologies (see Normand, Servières, & Moreau, 2012 for an overview). In the most known taxonomy, the Reality-Virtuality Continuum, AR is placed between the two extremes of real and virtual environment, leaning towards the side of the real environment (Milgram & Kishino, 1994). A newer taxonomy by Normand et al. (2012) classifies AR applications based on four axes, namely tracking (degrees of freedom and accuracy), augmentation type (optical see-through, video see-through, spatial augmentation), temporal base (past, present, future, time independent) and rendering modalities (beyond visual augmentation). With this taxonomy, AR applications can be classified depending on their goal and independent of the technology or the device used (Normand et al., 2012).

While the different definitions and taxonomies are often used independently of the research area, in the educational AR literature there have been attempts to connect AR to different learning theories and pedagogical approaches. Bower et al. (2014) and Dunleavy and Dede (2014) connect AR to situated and constructivist learning by assessing that learning with AR can take place at a relevant location and a deeper learning can occur with the support of AR. Game-based learning, in which immersion in the learning material is important, and inquiry-based learning, in which a scientific data gathering process is enacted, are also mentioned in connection to AR (Bower et al., 2014). In a review of the usage of learning theories to support the design of educational AR applications, Sommerauer and Müller (2018) mainly found that Mayer's multimedia principles from his Cognitive Theory of Multimedia Learning (Mayer, 2009), situated learning, game-based learning and simulations, and experiential learning were used in studies. Based on their findings, they furthermore developed a design framework that can be used for designing educational AR applications (Sommerauer & Müller, 2018).

While research on AR in education has been conducted for some time now, it is still not completely obvious how exactly AR is better for supporting learning than other learning technologies like tablet-based simulations or desktop learning environments. One key affordance of AR that Bower et al. (2014) mention is that with AR, students can rescale virtual objects of all sizes in order to better understand them. It is, however, not evident, how this is better than executing the same action on a tablet or desktop screen. Affordances of AR that are mentioned by Wu et al. (2013) and might also be true for technologies other than AR (for example a normal smartphone app), are ubiquity and situatedness, the visualization of the invisible and the bridging of formal and informal learning.

Although it is evident that these affordances all have the potential to support learning, it is not completely clear how exactly AR as a form of visualizing information plays a unique role in them. That is why, in the remainder of this paper, we aim to present and discuss three characteristics of AR that have been identified to be important factors in supporting learning. We describe how they are in this specific way only found in AR and not in other learning technologies, and thus reveal unique values that AR has for education, as proposed by Wu et al. (2013). Furthermore, we suggest that these three characteristics might provide a structure and a focus for educational AR research, to examine when and how the implementation of AR is most beneficial for education. This may help to develop a systematic research agenda for the use of AR in education scenarios and thus also support instructors and designers in developing effective AR-based learning experiences for various target groups and learning objectives in formal and informal learning settings. After the introduction and discussion of the three characteristics from a user's perspective in the next section, two studies that have been conducted on AR-supported learning are presented and discussed in the context of the characteristics. These studies exemplify how the three characteristics can be used for classifying and planning empirical research. A conclusion for the three characteristics and future research is drawn at the end of the paper.

2. Three Characteristics of AR from a User's Perspective

As stated by Hugues, Fuchs, and Nannipieri (2011), augmenting reality in itself is not possible, so that in AR a person's perception of reality is augmented. Therefore, we chose to look at the characteristics that AR possesses from a perceptual, user's perspective. In order to do this, we considered the three characteristics in the aforementioned definition of AR by Azuma (1997): (1) combination of the real world and virtual elements, (2) real-time interactivity, and (3) registration in 3D. The technology that delivers the AR experience to the user must possess these properties. In order to reframe the characteristics from a user's perspective, we looked at how they affect the user's experience of AR and propose three characteristics of the experience of using AR that cannot be found in this specific form in other technologies: contextuality, interactivity, and spatiality. In the following paragraphs, these three characteristics are described and their value for technology-enhanced learning is discussed. Also, four interesting research areas are given for each of the characteristics: two concerning individual learning, and two concerning collaborative learning. Table 1 shows an overview of the three characteristics.

2.1 Contextuality

In Azuma's (1997) definition, the first characteristic is that real world and virtual elements are combined in AR. From a technological perspective this means that virtual and real elements are displayed simultaneously. The displaying device must be context sensitive and aware of its location to show the user the digital content that is relevant at that place in that moment (Dunleavy & Dede, 2014). When looking at this characteristic from a perceptual, user's perspective, this means that the user perceives the displayed virtual elements (e.g., objects, pictures, text) in the context of the real world around them (e.g., physical objects, other learners). In contrast to virtual reality, the context is not completely covered by the virtual elements, and in contrast to information on a screen, the virtual element and the context are not separated from each other (Rekimoto & Nagao, 1995). With this, novel opportunities and challenges to link the context and the virtual elements appear. Therefore, the first AR-specific characteristics reframed from a user's perspective is "contextuality".

Concerning the benefits that contextuality has for learning, it can be said that with AR it is possible to situate learning in a relevant context, which may increase the authenticity and ground students in reality (Wu et al., 2013). Even though it may also be possible to look up information that is relevant to the place where the user is at that moment with mobile devices, in AR the possibility to overlay visual virtual information over the environment gives additional potential for "perfectly situated scaffolding" (Bower et al., 2014, p. 6). Here, the relationship between the real world and the virtual information is closer than when just looking at relevant information on a mobile device. Bower et al. (2014) call the ability to contextually overlay information onto the real world one of the key pedagogical affordances of AR and Dunleavy and Dede (2014) state that embedding learning within relevant environments is very likely to enhance learning. In scientific literature, there is furthermore a connection made between the contextuality of AR and Mayer's (2009) multimedia principles of spatial and temporal contiguity (Akçayır & Akçayır, 2017; Radu, 2014). Through contextuality, instructional information can be made available at the right place and time and can this way be situated inside the real world. This implements the contiguity principles, which state that information that belongs together should be presented in an integrated way and at the same time (Mayer, 2009) in order to avoid split attention and thus increased cognitive load (Ayres & Sweller, 2014). When working in a collaborative learning setting, the contextuality of AR can also be beneficial. In co-located collaboration, contextuality means that because the virtual elements do not occlude other learners and the context, virtual information can be added to face-to-face collaborative learning settings. Learners can then perceive virtual information, the other learners, and the context around them at the same time. Here, it must be considered that a complex interplay between the three elements takes place, which might have an influence on the collaboration between the learners and their references to learning material or other external artifacts (see Bodemer, Janssen, & Schnaubert, 2018; Stahl, 2006). In general, through the characteristic of contextuality, AR has the potential to apply some of the multimedia principles onto the real world and support especially the situating of learning in a relevant environment. This provides interesting opportunities for applying AR to support learning both inside and outside the classroom.

Different questions concerning the contextuality of AR that still need to be answered through empirical research are, for example: (a) Do people indeed learn better when they are in a relevant context than when they are not and which (cognitive, motivational, and emotional) factors play a role in this?, (b) How closely must the context and the virtual information be thematically related for the overlaying of information to be beneficial?, (c) How does the interplay between learners, contexts, and virtual material have an influence on the interactions between two or more learners learning collaboratively?, (d) What are the advantages and challenges of placing group awareness information (see Bodemer et al., 2018) about other learners directly next to the respective learner? Concerning this last question, a study is presented later in this paper (study 2).

2.2 Interactivity

The second characteristic that Azuma (1997) mentions in his definition of AR is that AR elements are interactive in real time. From a technological perspective this means that the elements must be programmed to react to input that the user or – in a collaborative setting – the users give.

From a perceptual, user's perspective this entails that users experience the virtual elements reacting to their and other learners' actions. In turn, all users can react to the element's actions. In AR, virtual elements have two interactive sides. Because virtual objects in AR are placed inside the real world, they lend themselves to natural and intuitive interaction that is not possible with screen-bound virtual objects (e.g., "real" touching, gesture-based interaction). On the other hand, users can manipulate the virtual AR objects in other ways than purely physical objects (e.g., input of new data to change simulations, control through input devices) and can receive realistic and immediate feedback upon their input. This way, the interactive capabilities of real and virtual elements are combined in AR. Billinghurst and Dünser (2012), for example, state that in AR books, different forms of interaction are possible, like turning real pages to change the virtual scenery or tilting and rotating the pages to view the virtual elements from different angles. Hence, users can interact with the digital content by manipulating real objects, using a tangible interface metaphor. Therefore, a second AR-specific characteristic reframed from a user's perspective is its "interactivity".

Concerning the benefits that interactivity has for learning, it was found that even the most intuitive form of interaction with an object (i.e., perspective changing by walking around it) can be advantageous for learning (Holmes, Newcombe, & Shipley, 2018). Following embodied cognition theory, whole-body interaction with AR learning material can also lead to better learning outcomes (Johnson-Glenberg & Megowan-Romanowicz, 2017). Concerning collaborative learning settings, it can be said that in AR all learners can interact with the virtual elements in the same way and can watch how other learners interact with them. With other learning technologies, one person controls the mouse and keyboard and others watch, or everybody uses their own device to collaborate online. In AR, learners and their actions can directly be linked to each other, which may support the forming of a mental model of the other learners and thus group awareness. In general, AR's interactivity provides interesting new ways to interact with learning material, supporting learning in different settings.

Questions that still need to be answered with empirical research concerning the interactivity of AR are for example: (a) How does AR-based interaction (using a tangible interface metaphor in which interaction with an AR marker in the real world leads to manipulation of virtual objects) have a different effect on learning especially the connections between objects in comparison to a more familiar touch-based interaction with virtual objects?, (b) How must interaction with the material be designed to evoke higher order thinking processes?, (c) What influence does the collaborative interaction with the AR material have on the interaction between learners?, (d) How does watching other group members interact with the material support understanding and for example grounding processes in the group?

2.3 Spatiality

The third characteristic mentioned in the definition is that virtual elements must be registered (i.e., placed) inside the 3D real world (Azuma, 1997). From a technological perspective this means that the real world must be tracked continuously, so that the virtual element can be pinned to a specific point in space. Also, the spatial specifics like the dimensionality of the element itself need to be defined.
From a perceptual, user's perspective this means that the virtual elements should seem to exist in the same space as the real world. When virtual objects are placed inside the 3D real world, they can appear

to have more spatial depth than virtual objects shown purely on flat screens. Pseudo-spatial visualizations are possible when using monocular depth cues on AR flat screens, while even true spatial visualizations can be created with the aid of binocular disparity when using AR glasses (Jeřábek, Rambousek, & Wildová, 2015). The third AR-specific characteristic reframed from a user's perspective, is thus its "spatiality".

Concerning the benefits of spatiality in educational settings it can be said that physical 3D objects were found to be better for learning than 3D computer models (Preece, Williams, Lam, & Weller, 2013). When looking at the spatial properties of 3D AR models, they lie between physical and computer models, so that they may also be more beneficial for learning than normal computer models. Advantages concerning the mental load of participants using a 3D visualization to learn a visual motor task over using a 2D visualization could also be found (Dan & Reiner, 2017). AR might be especially useful for learning the spatial structure of 3D material (Radu, 2014) and subjects with a spatial component are learned more effectively with AR (Billinghurst & Dünser, 2012). In collaborative learning settings, an example of how the fixation of an AR object to a point in space can be used is through knowledge sharing by tagging and annotating objects (Specht, Ternier, & Greller, 2011). The objects over which the learners collaborate or which they create collaboratively can also be three-dimensional and fixed to one point in space. This may offer various advantages over working together on two-dimensional screen-based material. In general, it can be said that learners may especially benefit from AR's spatiality when learning about spatial structures and relationships.

Questions that arise and should be answered through empirical research are for example: (a) Is using a three-dimensional AR object as beneficial for learning spatial structures as real objects are, in comparison to screen-based objects?, (b) How much does the use of stereoscopic AR glasses in comparison to screen-based monoscopic AR influence the spatial perception of an object and what are the advantages concerning the spatial understanding the user acquires about it?, (c) Does the collaborative creation of a three-dimensional artefact lead to better learning than the creation of a two-dimensional artefact?, (d) How exactly does using a whole room as a space to learn in together instead of a shared screen influence the interaction with the material and between the learners?

Table 1

Three Characteristics of AR from a User's Perspective

Azuma's characteristic	**User perspective characteristic**	**Description**
Combination of the real world and virtual elements	Contextuality	▪ users perceive virtual elements simultaneously with real world (including other users) around it ▪ users do not perceive virtual elements and context (including other users) separately
Real-time interactivity	Interactivity	▪ users experience virtual elements reacting to them and other users, and experience themselves and other users reacting to actions of the elements ▪ interactive properties of physical AND virtual elements
Registration in 3D	Spatiality	▪ virtual elements placed inside the 3D real world appear as if they were really there ▪ virtual elements appear more spatial than if shown on screen

2.4 Interplay of the three characteristics

The three characteristics of AR and their advantages for educational settings are not only interesting on their own, but also in their combination into one experience. Moving around a virtual AR object and looking at it from all perspectives, for example, concerns both interactivity and spatiality of AR. When the object stays in one place, it reacts to the user's movement (interactivity), which is possible because the object is fixed to a point in 3D space (spatiality). The authenticity of an experience can also be influenced by all three characteristics. Authenticity can imply the placement of a virtual object in a relevant, authentic environment (contextuality). It can also refer to the authenticity of the object itself, including its 3D presentation (spatiality). Furthermore, authenticity may imply authentic interaction with the virtual object (interactivity). An authentic virtual object placed in a relevant, authentic real-world environment and with authentic interactive properties, may provide the most authentic experience for learners.

This shows that the three characteristics cannot always be considered separately but can interact with each other. It is important to examine them through experimental research both separately and in interaction, to get an overarching picture of how AR can be used best in educational settings. In the following sections, we present two experimental studies that we executed concerning the use of AR in different educational settings: study 1 as an example of considering different characteristics (interactivity and spatiality) in an individual setting, study 2 as an approach of systematically varying one of the proposed characteristics (contextuality) in a collaborative setting. This way, two quite different ways of using the characteristics to structure and design empirical research are presented.

3. Study 1: Interactivity and spatiality in an individual setting

The first experimental study is based on research about learning with computer simulations. Using computer simulations paired with inquiry-based learning instructions like scientific discovery learning proved to be valuable in many ways for the learner to comprehend complex concepts in research contexts and practical applications (de Jong, 1991; de Jong & van Joolingen, 1998). AR applications for learning purposes can also be understood as (interactive) computer simulations or visualizations, but research about learning with AR applications rarely explored the fact that traditional and AR simulations share common concepts but differ in various aspects. It is unclear whether the learning benefits in working with AR applications found in these studies were due to the AR aspect of the application or because the learning material was a simulation or interactive visualization instead of traditional paper and text. The aim of this study was to compare a traditional (tablet-based) computer simulation with an AR version of the application with regards to their effects on conceptual knowledge, cognitive load, motivation, and spatial abilities of the learners. Although the study was not planned based on the three proposed characteristics, when comparing the AR and non-AR applications used, it shows that interactivity and spatiality differ between them. Concerning interactivity, it can be said that while in AR the users moved around the simulation and interacted with a real object (AR marker) to manipulate it, in the traditional simulation they used touch-based drag-and-drop on a tablet. Spatiality differed in the two applications in that virtual AR objects appear to be more spatial because the user has the reference of the real world, while this is not the case in a normal screen-based simulation.

3.1 Method

For this study, two almost identical computer simulations were developed and compared in an experimental laboratory setting: a normal computer simulation of a power plant on a tablet, and an AR simulation with AR markers and the tablet as a video-see-through display for AR elements. The two simulations differed regarding their interactivity and spatiality as described in the previous paragraph. During the experiment the participants ($N = 56$) followed a scientific discovery-based learning script with the goal of comprehending the underlying concept of power plants by building their own, changing the composition of the plant components, and first hypothesizing and then observing the outcome. The participants were randomly assigned to use either the traditional ($n_t = 28$) or the AR simulation ($n_{AR} = 28$). It was hypothesized that after the interaction with the material, participants have equivalent conceptual knowledge and cognitive load during the learning process as well as improved spatial abilities and motivation when learning with the AR simulation compared to the traditional simulation. Based on this, three TOST equivalence tests and five t-tests were executed to analyze the data.

3.2 Results

The equivalence tests were all executed for the equivalence bounds Cohen's $d = +/-0.67$, based on the smallest detectable effect with this sample size. The hypothesis that conceptual knowledge was equivalent in the two simulations could be supported ($M_t = 12.79$, $SD_t = 3.06$; $M_{AR} = 12.64$, $SD_{AR} = 2.84$), 90% CI for d [-0.40;0.49], lower bound, $t(54) = 2.69$, $p = .005$, upper bound, $t(54) = -2.33$, p

= .012. An equivalence of intrinsic cognitive load in the simulations was also found (M_t = 4.88, SD_t = 1.95; M_{AR} = 5.02, SD_{AR} = 1.98), 90% CI for d [-0.52;0.38], lower bound, $t(54) = 2.25$, $p = .014$, upper bound, $t(54) = -2.76$, $p = .004$. For extraneous cognitive load, equivalence in the simulations could not be concluded (M_t = 1.21, SD_t = 1.35; M_{AR} = 1.58, SD_{AR} = 1.42), 90% CI for d [-0.72;0.18], lower bound, $t(54) = 1.50$, $p = .070$, upper bound, $t(54) = -3.52$, $p < .001$. Based on three t-tests, no significant differences were found between the groups for these three variables.

The hypothesis concerning the difference in the resulting spatial abilities was not supported, as no significant difference between the traditional (M_t = 7.96, SD_t = 4.15) and the AR simulation (M_{AR} = 9.07, SD_{AR} = 5.00) was found, $t(54) = -0.90$, $p = .371$, $d = -0.25$. Contrary to expectations, motivation did also not differ between the two forms of simulation: intrinsic motivation (M_t = 5.51, SD_t = 1.18; M_{AR} = 5.78, SD_{AR} = 0.94), $t(54) = 0.94$, $p = .352$, $d = 0.26$, identified regulation (M_t = 4.61, SD_t = 1.30; M_{AR} = 5.14, SD_{AR} = 0.99), $t(54) = -1.73$, $p = .089$, $d = -0.47$, external regulation (M_t = 4.69, SD_t = 0.98; M_{AR} = 4.46, SD_{AR} = 1.00), $t(54) = 0.88$, $p = .382$, $d = 0.24$, and amotivation (M_t = 2.58, SD_t = 1.18; M_{AR} = 2.19, SD_{AR} = 1.18), $t(54) = 1.25$, $p = .217$, $d = 0.34$.

3.3 Discussion

The results of this study indicate that just transferring a desktop simulation into an AR simulation and thus manipulating interactivity and spatiality together might not be enough to be more beneficial for the learner regarding conceptual knowledge, motivation, cognitive load and spatial abilities. After using the application, the participants learning with the AR simulation had equal conceptual knowledge and intrinsic cognitive load and nearly equal extraneous cognitive load as the participants using the traditional simulation. The groups did not differ in motivational aspects and spatial abilities. Still, this experiment can serve as an initial study to find out more about how the three characteristics influence learning. In this study, both interactivity and spatiality were manipulated in the applications. To find out more about the specific benefits the two characteristics and their interaction have on learning processes and outcomes, more systematic studies are necessary in which interactivity and spatiality are varied separately. Furthermore, AR offers other possibilities than the ones varied in this study. A procedural simulation or visualization where the learner can use the application directly in the environment where the knowledge domain is registered (based on the characteristic of contextuality) might be more beneficial to the learner regarding learning outcomes and learning related variables. This also requires more research in the form of an experiment with systematically manipulated predictor variables.

4. Study 2: Contextuality in a collaborative setting

A further experimental study that was systematically planned and executed based on one of the three characteristics has focused on how to use the potential of AR's contextuality in a collaborative setting. Due to contextuality, the user can perceive virtual information, other learners, and the environment simultaneously. This way, virtual information can be shown exactly at the right time and place. As suggested by Radu (2014), this characteristic can be connected to Mayer's (2009) multimedia principles of spatial and temporal contiguity which state that information that belongs to each other should be presented at the same time and close to each other, preventing the splitting of attention and decreasing extraneous cognitive load. In computer-supported collaborative learning (CSCL), group awareness tools (GATs) can be used to support collaborative learning processes (Bodemer et al., 2018). As GATs provide contextual information about the social learning environment, it is crucial that they do not divert attention from germane learning activities. When group awareness (GA) information about other learners is visualized in face-to-face collaborative settings, this information is often printed out or shown on a screen, which means that the given information is separated from the context in which it is relevant (i.e., the collaboration with the other person) due to the medium that delivers it. This could especially be a problem in bigger groups of learners, because the correct GA information must still be connected to the right person. AR's unique characteristic of contextuality provides the opportunity to show GA information directly next to the corresponding person. Similar to the work of Holstein, Hong, Tegene, McLaren, & Aleven (2018), where teachers were provided with real-time information about their students' learning process through augmented reality glasses, this GA information could be presented directly over or next to the corresponding student. In this study, the systematic variation in the two conditions was thus based on contextuality so that in the AR condition the information and the context were integrated, while in the non-AR condition they were separated from each other. The aim of the study was to find out whether placing information about people directly next to them in comparison to placing it further away has an influence on cognitive load and retention of the information.

4.1 Method

To compare the visualization of GA information next to people and further away from them, we used pictures instead of a real implementation in AR to investigate the characteristic of contextuality in a controlled laboratory setting. In the study, the participants (N = 38) worked on tasks in which they had to form study groups of the people shown to them in pictures based on the GA information given about them. The participants were randomly assigned to one of two conditions: GA information visualized directly next to the corresponding person in the picture (AR mockup; nAR = 18) or GA information shown separately below the pictures (nnonAR = 20). In the different tasks given to the participants, the number of people shown to them was varied between two and ten people to see if an effect of the proximity of the information differs with a differing number of people. The two independent variables were thus the proximity of the information to the people (between-subject) and the number of people displayed (within-subject). It was hypothesized that these two factors and their interaction influence the cognitive load of the participants as measured continuously through a secondary reaction task and the efficiency in executing the task as measured by their time spent on the task. Furthermore, it was expected that the proximity of the information influences the participants' self-reported extraneous cognitive load and their recall of the GA information. Two mixed-design ANOVAs and two independent samples t-tests were used to analyze the data based on these hypotheses.

4.2 Results

The hypothesis that the proximity of the information has an influence on the continuously measured cognitive load could be supported with a significantly slower reaction time (ms) in the group where picture and information were shown further apart (MnonAR = 2197.83, SDnonAR = 1863.29; MAR = 1153.49, SDAR = 744.64), F(1,36) = 4.93, p = .033, ηp2 = 0.12. The same pattern was found for the time spent on the task, where the group with the separate information presentation needed more time (s) to solve the tasks than the group with the integrated visualization (MnonAR = 62.86, SDnonAR = 19.76; MAR = 50.93, SDAR = 11.11) , F(1,36) = 5.11, p = .030, ηp2 = 0.12. Concerning the within-subject factor (number of people), it can be said that even though more people shown generally meant both a longer time spent on the task, F(1.24, 44.44) = 21.11, p < .001, ηp2 = 0.37, and a longer reaction time in the secondary task, F(2.531, 91.13) = 4.933, p = .005, ηp2 = 0.12, this pattern was not found for all pairwise comparisons. No significant interaction effect was found for reaction time, F(2.53, 91.13) = 1,47, p = .233, ηp2 = 0.04, or time spent on the task, F(1.24, 44.44) = 1.25, p = .279, ηp2 = 0.03.

Concerning the variables that were not measured for every single task, no significant difference was found in either self-reported extraneous cognitive load (MAR = 4.07, SDAR = 1.68; MnonAR = 4.25, SDnonAR = 1.67), t(36) = -0.32, p = .748, d = -0.11, or recall of the GA information between the two groups (MAR = 2.39, SDAR = 1.29; MnonAR = 2.20, SDnonAR = 1.11), t(36) = 0.49, p = .630, d = 0.16.

4.3 Discussion

In this study, in which contextuality was varied systematically, significant differences between the two groups concerning the reaction time in a secondary task and the time on task were found. The participants in the AR mockup group needed less time for solving the tasks and reacted faster on the secondary task, which shows that they were more efficient and less cognitively occupied in their task of forming study groups based on the information about the people. However, these results could not be supported by the results in the self-reported cognitive load and recall of the information, which did not differ between the groups. A confounding variable that might have led to the differences in the timings between the groups was that the participants from the non-AR group had to scroll down on the pages with the tasks, while the others did not. In a future study, this factor must be held stable between the groups. Also, other objective measures for cognitive load, which should not be influenced by scrolling (e.g., eye-tracking metrics), might be used to compare the two forms of visualization in a future study. A factor that may have led to less differences between the groups is that the tasks could be solved without even looking at the pictures of the people. This way, the participants might not even have made the connection between the people and the information. Split attention only happens when one part of the material is not understandable without the other (Ayres & Sweller, 2014). This was not the case here and an adapted study design should be considered for future studies.

5. Conclusion

In this paper, three characteristics of AR are reframed from a user's perspective and discussed in relation to their potential for supporting individual and collaborative learning. It is proposed that these three characteristics can be used as a basis for researching AR in educational settings and two studies which have been executed with the three characteristics in mind are presented.

The two studies differed considerably in their usage of the characteristics. In study 1, the experimental manipulation can be classified into two of the characteristics, namely interactivity and spatiality. Concerning this study, we conclude that to get a more complete picture, follow-up studies are necessary in which the two characteristics are varied separately and systematically. This way, their influence on learning processes and outcomes can be determined. In study 2, a systematic experimental variation based on the characteristic of contextuality took place and positive effects on efficiency and cognitive load could be found. Due to confounding variables, the results of the study should be interpreted with caution. Follow-up studies that control for these factors are needed to confirm the results concerning the increased efficiency and decreased cognitive load in the setting.

While contextuality, interactivity, and spatiality all seem to be important for using AR in educational settings, more systematic empirical research concerning their potentials, their impact and their interplay is necessary. Based on the two presented studies, which initialized the research on AR in education at our lab, more empirical studies with systematic variations based on the three characteristics are currently conducted and planned, such as two experimental studies that intend to systematically disentangle the characteristics of interactivity and spatiality.

AR-supported learning experiences have the potential to be applied in different settings and with various goals, which can also be seen in the differences between the two presented studies. Thus, systematic AR-related research findings can enrich the design of formal and informal educational environments for individual and social learning of diverse students. In order to provide a structuring basis for this heterogeneous research field, the three characteristics contextuality, interactivity, and spatiality are proposed to serve as common denominators for the users' experience of AR in a wide range of learning settings.

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