

Effect of augmented reality environments on cognitive load: pedagogical effect, instructional design, motivation and interaction interfaces

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Abstract

The aim of this study was to explain the relationship between cognitive load and the effects of augmented reality (AR) learning environments. To achieve this aim, firstly, the studies of systematic literature reviews on the potential and limitations of AR learning environments were examined. Afterwards, the effect of AR was categorized in terms of (1) pedagogical effect, (2) instructional design, (3) motivation and (4) interaction interfaces. Finally, the relationship between cognitive load and the emerging categories related to the potential and limitations of AR was explained and recommendations were presented. From a pedagogical point of view, AR helps to reduce extraneous cognitive load and to increase germane cognitive load. On the other hand, the effect of AR systems, which are difficult to use and complex in terms of instructional design, on cognitive load was revealed. Some teaching methods and design principles that can be effective as solutions were presented. In addition, the effects of motivational stimuli on the prevention or extension of cognitive capacity among students were described. Finally, the potential and limitations of AR interaction interfaces on cognitive load were explained. The results of this research provide important clues for AR developers and instructional designers in terms of reducing cognitive load and the elimination of working memory limitations.

Keywords: Augmented reality, cognitive load, instructional design, interaction interfaces, pedagogy, motivation

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INTRODUCTION

Cognitive load theory is based on human cognitive architecture (sensory, study and long-term memory) and attempts to explain how the information-processing load, which emerges during the teaching of new information, affects students' knowledge processing and structuring knowledge in long-term memory (Sweller, Merriënboer & Paas, 2019). According to this theory, teaching activities play an important role in increasing the capacity of working memory and eliminating limitations. As the capacity of working memory is limited, information is retained in the memory for a short time (Young et al., 2014). Long-term memory has an unlimited capacity, with bits of information structured as schematics there. Working memory has a strong relationship with long-term memory (Wernaart, 2013). Long-term memory stores previously acquired information, while working memory deals with the processing of information before or after long-term storage. The newly learned information is first processed by working memory which is limited in terms of time and capacity, then transferred to long-term memory for reuse. On the other hand, when well-structured information in long-term memory is transferred to working memory, the latter has no time limit (Sweller, Merriënboer & Paas, 2019). For this reason, the capacity of working memory and the time limitation should be taken into consideration in the teaching of new knowledge. Working memory performance is negatively affected by learning when there is excessive cognitive load (Paas, Van Gog & Sweller, 2010). However, as an individual's expertise develops in a field, the number of interactive elements created by a particular task will decrease as will cognitive load (Sweller, Ayres, Kalyuga & Chandler, 2003; Renkl & Atkinson, 2003). As students gain expertise, they will be able to perform more complex tasks. Expertise is related to well-structured information held in long-term memory which is useful to learning tasks (Paas, Van Gog & Sweller, 2010). On the other hand, complexity or elemental interaction depends on both the quality of information in long-term memory and the characteristics of the person who processes the information. For experts, the minimum elemental interaction occurs, whereas, for novices, the number of interactive elements is high (Sweller, Merriënboer & Paas, 2019).

The amount of elemental interactions in memory corresponds to the number of interactions with the schemas in working memory, when students are conducting cognitive activities (Chandler & Sweller, 1996). According to Van Merriënboer, Durning and Ten Cate (2014), this significantly reduces the load of working memory by organizing the information elements of the schemas defined as area-specific information elements and their relationship with each other. Schemas are generally constructed by germane load through activities such as interpretation, sampling, classification, inference, distinction and organizing (De Jong, 2010). According to Costley and Lange (2017), germane load creates schemas for dealing with interacting elements and for a better understanding of the information in working memory. The researchers also stated that the difficulty level of a task will not change, even if a task about non-schematic information is addressed and reconsidered.

Elemental interactivity depends on the schemas in long-term memory. For this reason, the nature of the task cannot be altered because it is unable to be manipulated by instructional design (Ayres, 2006). However, as there is less need for the resources of working memory in tasks where fewer elements interact, teaching can be made easier and delivered faster. On the other hand, as elemental interactivity increases, cognitive activities that need to be processed simultaneously in working memory increase as well. Therefore, learning will be more difficult and slower (Paas, Van Gog & Sweller, 2010).

Sweller (2010) stated that elemental interactivity will remain in the shadow of the extraneous cognitive load when the latter is excessive. The total intrinsic and extraneous cognitive load can match the capacity of working memory, so the integration of extra elements within existing information cannot be realized (Leppink & Heuvel, 2015). As a student's expertise increases, working memory can be integrated into elements with large, complex information networks and in-depth learning can be realized (Cooper, 1998). According to Debue and Leemput (2014), expertise not only consists of general problem-solving skills or the ability to analyze new pieces of information from working memory, it is also based on the ability to perceive well-organized schemas in long-term memory. As novices will associate knowledge with a large number of existing elements in their mind, individual

learning performance will be low. Expert learners, however, will be able to interact with a few more well-organized elements in long-term memory, meaning that learning performance will be faster and the working memory load will be reduced. In other words, since some elements of knowledge are already a part of expert students' cognitive schemas, there will be less elemental interactivity (Leppink & Heuvel, 2015). For this reason, low motivation and concentration may be sufficient for expert students to learn (Young et al., 2014).

Sweller (2010) divides the cognitive load that occurs during learning into three groups: intrinsic, extraneous and germane. Intrinsic load, also referred to as task complexity, arises from the number of task elements and their interaction with each other (Sweller, Van Merriënboer & Paas, 1998; Costley & Lange, 2017). According to Ayres (2006), this depends on the natural complexity of a topic, as well as on the level of individual competence, the number of elements related to the task, and the level of interpersonal interactions between learners in a group setting.

Extraneous cognitive load occurs due to poor instructional design and refers to mental activities that either cause unnecessary processing in working memory or do not contribute to learning (Costley & Lange, 2017; Debue & Leemput, 2014; Leppink et al., 2013; Wernaart, 2013). The mental activities and information that make use of a learner's working memory capacity serve as a contributing factor for cognitive load when caused by poorly designed teaching procedures, which prevent schema formation or result in automation (Paas, Van Gog & Sweller, 2010). Therefore, extraneous load should be kept as low as possible.

Finally, germane load refers to mental resources that help to create and automate long-term memory schemas (Kirschner, 2002). According to Ayres (2006), if extraneous load is not reduced in order to avoid exceeding working memory resources, germane load should be encouraged in order to increase learning. Germane load refers to the sources of working memory needed to deal with intrinsic cognitive load. Unlike intrinsic and extraneous load, germane load is more beneficial for the learning process (Costley & Lange, 2017; Cierniak, Scheiter & Gerjets, 2009). In addition, the germane cognitive load affected by the instructional design can be interpreted as an indicator of the level of understanding of the content that directly contributes to learning (Ayres, 2006; Young et al., 2014). Sweller et al. (1998) observe that some teaching methods have the capacity to reduce cognitive load and increase learning. As a result, the researchers conceptualized germane cognitive load. In contrast, Schnotz and Kürschner (2007) explain that germane load is not compulsory for learning to take place, but it may improve the learning process.

Instructional control of cognitive load

Instructional control over cognitive load is critical for meaningful learning (Sweller, 2010). However, in order to increase teaching potential due to the inability of intrinsic load to be influenced by the instructional design, teaching activities should be carried out to reduce extraneous load and increase germane load. This results in a scenario where the higher the rate of germane cognitive load, the greater the learning potential. If intrinsic load is high, the memory capacity to be allocated to the extraneous load in working memory will be reduced in order to increase the mental effort. When extraneous load is reduced, the use of working memory and germane cognitive load should, in turn, increase, in order to deal with intrinsic cognitive load. As working memory has the potential to increase germane load, the former's resources should be organized in such a way as to control for intrinsic load by supporting germane load (Ayres, 2006).

On the other hand, if extraneous load increases, fewer working memory resources will be allocated to the relevant elemental interaction in long-term memory; for this reason, germane cognitive load will be reduced (Paas, Van Gog & Sweller, 2010). If intrinsic load is reduced and extraneous load remains within the working memory limits of the student, learning will not be damaged, as germane load processing activities will continue to proceed (Carlson, Chandler & Sweller, 2003). However, when the total cumulative intrinsic and extraneous load approaches or exceeds the operational memory limits, the working memory resources for germane load will be insufficient while the processing

activities of the same load will be prevented. In such a case, learning will be negatively affected, given that learning problems, such as combining new knowledge elements with existing schemas in long-term memory, will occur (Debue & Leemput, 2014). The student may be bored because the internal load will be very low. In other words, if the student's attention to learning is reduced, learning will be inhibited (Leppink & Heuvel, 2015).

One of the strategies to reduce cognitive load is to reduce the number of interactive elements in working and long-term memory. According to this method, given that simplifying the instruction should be pursued in the first place, the number of element interactions should be reduced. As successful elemental interactions actualize and as the student gains expertise, cognitive load can be increased and new teaching elements can be added, so as to avoid exceeding the capacity of working memory (Huang, Liu & Tsai, 2013; Van Merriënboer, Kester & Paas, 2006; Sweller, 2010).

AR is a class of technology in which real and virtual images are presented together, by incorporating digital content into real media images simultaneously taken from the camera (Billinghurst, Kato & Poupyrev, 2001). On the other hand, Cognitive load theory is one of the most important theories that should be considered by instructional designers. This theory refers to the cognitive processes of the user in the use of technology (Lee & Wong, 2014). As such, the instructional designer needs to consider the cognitive load of the user by going beyond the technological features (Sweller et al., 1998). The positive contribution of AR to cognitive load has been frequently demonstrated in studies on the former's use in education (Akçayır & Akçayır, 2017). Research has revealed that AR is an important determinant in cognitive load in terms of pedagogical effect, instructional design, satisfaction and usability perceptions, interaction interfaces and gender factors.

Within the scope of this research, the answers to the following research questions were sought:

- (1) What are the results of the systematic literature reviews regarding the potential and limitations of AR learning environments?
- (2) What are the effects of AR's pedagogical contributions on cognitive load?
- (3) What are the effects of AR instructional design on cognitive load?
- (4) What are the effects of motivational stimuli in AR environments on cognitive load?
- (5) What are the effects of AR's interaction interfaces on cognitive load?

METHOD

The first task in this research was to examine systematic literature reviews from 2014 to 2019, which are focused on the potential and limitations of AR in learning environments. Therefore, in order to determine how researchers evaluated the effectiveness of AR systems in these previous reviews, a new systematic literature review was conducted. Various methods are used by researchers in order to ensure that the number of articles is manageable and to create a methodologically robust and scientifically consistent process in systematic literature survey studies (Akçayır & Akçayır, 2018). In this study, firstly, inclusion and exclusion criteria were determined for the articles to be reviewed, as shown in Table 1.

Table 1. The criteria of Inclusion and Exclusion

Inclusion	Exclusion
The last 6 years (2014-2019)	Studies outside these dates or time period
Written in English	Written in languages other than English
AR in Education	AR outside of education
Clear research design, findings and conclusions	Unclear research design, findings and conclusions.

The titles and abstracts of the articles indexed on Google Scholar, using the key search terms in Table 2, were reviewed according to these criteria.

Table 2. Searching string used in the systematic review

“augmented reality”	“systematic literature review” OR “systematic review” OR “literature review”	“education” “learning” “teach”
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Google Scholar was used in the study because it allows for relatively easier access and downloading more publications which are focused on the use of AR in educational environments. Studies which did not meet the selection criteria were not included in the research. After the completion of the literature review, the full texts of the 13 studies that passed the screening stage were downloaded (Table 3).

Table 3. Selected papers into Scoping Review

Author	Year
Bacca, Baldiris, Fabregat and Graf	2014
Diegmann, Schmidt-Kraepelin, Eynden and Basten	2015
Saltan and Arslan	2016
Swensen	2016
Akcayir and Akcayir	2017
Fotaris, Pellas, Kazanidis and Smith	2017
Li, Van der Spek, Feijs and Wang	2017
Sommerauer and Müller	2018
Hedberg, Nouri, Hansen and Rahmani	2018
Yuliono, Sarwanto and Rintayati	2018
Silva et al.	2019
Quintero et al.	2019
Herpich, Nunes, Petri and Tarouco	2019

The findings, discussion and conclusion sections of these studies were examined by content analysis, and categories were determined for the potential and limitations of AR in learning environments. Accordingly, four main categories were created: pedagogical effect, instructional design, motivation and interaction interfaces.

After the categories were determined, studies containing the search terms “augmented reality” and “cognitive load” were revised by using Google Scholar. During the review, the titles and summaries of experimental and theoretical studies explaining the effect of AR on cognitive load were grouped according to the above-mentioned four categories. Finally, the findings, discussion and conclusion sections of all categorized articles were examined in detail, and a conceptual framework for the effect of AR on cognitive load was presented.

RESULTS

In this section, first of all, the findings obtained by examining previous systematic literature surveys on the potential and limitations of AR learning environments are presented. Then, the relationship between cognitive load and potential/limitations of AR learning environments, which were collected according to the four categories, was discussed.

Potential of AR in teaching environments

Bacca, Baldiris, Fabregat and Graf (2014) performed a systematic review of publications on AR and education. The researchers emphasized three features of AR, i.e., learning gain, motivation and facilitation of interaction. In addition, they stated that the most frequently emphasized limitations of AR were those on the instructional design of systems. Similarly, Akçayır and Akçayır (2017) conducted a systematic review of 68 publications in SSCI journals related to the use of AR in education and classified the advantages of AR in related publications into three categories: learner outcomes, pedagogical contributions and interaction. Yuliono, Sarwanto and Rintayati (2018) classified AR's contribution to learning environments according to three main topics. The first refers to learner outcomes, including motivational elements such as motivation, positive attitude, skills, knowledge and understanding, learning effectiveness and satisfaction. The other two topics are pedagogical contributions and interactions. Quintero et al. (2019) analyzed articles related to the use of AR in education in their systematic literature review. These researchers stated that AR's contributions to motivation, interaction and personalized learning were more prominent. Herpich, Nunes, Petri and Tarouco (2019) conducted a systematic review of educational studies published between 2011 and 2018 on mobile AR applications. Researchers have demonstrated the pedagogical potential of AR in their own work, while highlighting that the effect of AR on learning approaches, such as collaborative learning, inquiry-based learning, learning styles and blended learning, is frequently investigated in others' studies. Saltan and Arslan (2016) conducted a systematic review of research on the education AR applications on the Eric database. The researchers stated that AR facilitates situational learning, inquiry-based learning, cooperative learning and game-based learning, which is related to AR's specialties of knowledge comprehension/acquisition, concept development and knowledge retention. Thus, they emphasized AR's pedagogical aspect in educational environments and stated that AR supports motivational elements such as attention, engagement, interest, motivation, satisfaction, enjoyment and autonomy. Diegmann, Schmidt-Kraepelin, Eynden and Basten analyzed 25 experimental studies and identified 14 different benefits of AR, grouping them into six categories. One of these is state of mind, which includes motivational elements such as motivation, attention, concentration and satisfaction. Another important category is teaching concept, which emphasizes the pedagogical effects of AR, such as student-centered learning and collaborative learning. Presentation is the category that includes interactivity, which is one of the most important features of AR. The other three main categories are learning type, concept understanding and reduced cost. Fotaris, Pellas, Kazanidis and Smith (2017) conducted a systematic review of 17 studies on motivation and performance among elementary school students in the case of game-based AR applications. The researchers stated that more than half of the studies emphasized that AR improves learning performance, and that a significant portion of them find that students' motivation, class participation and perceived entertainment are increased. Li, Van der Spek, Feijs, Wang and Hu (2017) explored the current state of game-based AR applications and presented a systematic literature review by examining 26 studies. The researchers classified the effects of game-based AR on learning achievement according to two main topics: (1) achievement of learning gains and (2) motivation. As in our study, they also gathered elements such as fun, interest, enjoyment, engagement, satisfaction, willingness, attitude, attention and confidence under the motivation heading. Researchers have also grouped the collaborative and interactive features of AR under three main categories: student-student, student-teacher guidance, student-parental guidance. Hedberg, Nouri, Hansen and Rahmani (2018) analyzed 73 articles, finding that, in one third of them, AR technology was found to improve students' work performance, while more than half reported that AR increases students' motivation and class participation. The other learning outcomes in the studies were stated as the development of cooperation skills, creativity and problem-solving skills (<10%). In terms of pedagogical approaches, they reported that AR was mostly investigated with regard to interactive learning, inquiry-based learning and cooperative learning. Swensen (2016) classified the educational effect of AR use in science education into four categories: (1) cognitive effort, (2) motivation, (3) situated learning and (4) inquiry-based learning. Silva et al. (2019) conducted a systematic literature review on the potential of AR use in education in the case of 45 articles found on the IEEE, ACM and ScienceDirect databases, covering the period between 2009 and 2017. They reported that more than half of these studies

investigated the impact of AR on knowledge retention or performance, with half considered its usefulness. Unlike other studies, the usefulness heading includes emotions such as attitude and satisfaction, according to Silva et al.'s (2019) findings. When the researchers examined other motivational elements under the heading of behavior and motivation and evaluated approximately 20% of the relevant studies, they discovered that teaching types were never mentioned in about 50% of the studies, while, in the cases where teaching approaches were stated, the most frequently investigated approaches were situated learning, multimedia learning, cognitive load, learning styles and mobile learning approaches.

Findings on the limitations of AR in teaching environments

Quintero et al. (2019) stated that visual and auditory problems as well as technical problems are the most common limitations in research. Similarly, Saltan and Arslan (2016) found that instructional design and technical problems are often cited as limitations in research investigating the effectiveness of AR in learning environments. On the other hand, Herpich, Nunes, Petri and Tarouco (2019) revealed that the limitations of AR were hardly investigated. In the studies where limitations were expressed, it was noted that the instructional design of AR was generally limited to the ability of researchers and that a systematic instructional design and learning method was not followed. Hedberg, Nouri, Hansen and Rahmani (2018) pointed out that the majority of studies do not specify which pedagogical approach was used. Sommerauer and Muller (2018) found that the majority of empirical studies on AR education and learning theories do not take into account these theories and design principles in a systematic way. Fotaris, Pellas, Kazanidis and Smith (2017) stated that one of the most common limitations in education and AR research was that teachers were unable to effectively use AR teaching materials, while, by focusing more on virtual manipulations, some students' attention was reduced. In addition, researchers have indicated that AR's technical and instructional design problems are often mentioned as limitations in the literature. Li, Van der Spek, Feijs, Wang and Hu (2017) acknowledged that children playing AR games could face time constraints because they are more easily and more frequently distracted. The researchers proposed that this situation is a limitation in studies.

Although the findings on the potential of AR in teaching environments are similar, as can be seen in the systematic literature surveys related to AR and education as stated above, classification categories can change. However, the common point of many studies is that AR makes significant contributions in terms of pedagogy, motivation and interaction. For this reason, the effect of AR on teaching environments was allocated to these three headings. The pedagogical heading includes the importance of AR to teaching approaches as well as its instructional effectiveness. The motivation heading includes motivational procedures such as fun, interest, enjoyment, engagement, satisfaction, willingness, attitude, attention and confidence. The interaction heading is concerned with student-teaching material, student-student and student-teacher interactions. In the case of AR in instructional environments, it can be seen that important limitations are instructional design limitations, such as software, usability, interface design, device ergonomics, limited time and guidance.

Pedagogical effect of AR on cognitive load

Pedagogy is the preparation and implementation of educational activities within certain theoretical rules, under the direction of some moral and philosophical purposes (Wang, & Huang, 2018). For this reason, it is always necessary to examine technology and its tools in order to develop pedagogical techniques. In this section, the relationship between AR and cognitive load is considered from a pedagogical perspective.

Physical manipulators are the symbolic representations of abstract information and serve as a bridge to connect with abstract concepts (Chandrasekera, 2014). Physical manipulators can facilitate collaborative interaction with learners and teaching content, and provide an active learning environment by allowing students to progress at their own pace and in the way they prefer (Saitta,

Gittings & Geiger, 2011). Through this collaborative learning environment, students can acquire different perspectives and learn more deeply about different aspects of educational content (Chi, 2009). AR has been found to offer considerable potential to create collaborative learning environments (Matcha & Rambli, 2011; Klopfer, Perry, Squire & Jan, 2005). On the other hand, similar to physical manipulators, AR manipulators can also serve as a similar bridge in spatial and temporal terms, helping students to understand the relationships between solid objects and their representations. The information can be updated depending on the student's progress, and the concepts that are difficult or impossible to achieve with physical manipulations can be transferred more easily to the student (Chandrasekera, 2014).

AR tools can collect information from a variety of sources while working in different environments, as well as transfer this information without interruption (Hogg, 2012). Physical manipulations may occasionally distract the student and the concepts represented may be missed (Brown, McNeil & Glenberg, 2009). AR materials can direct students' attention towards a specific target point (Billinghurst, Kato & Poupyrev, 2001). Thus, it can alleviate mental complexity, attract the attention of students, and direct them to investigate or interrogate (Moyer et al., 2002). Considering that our brain cannot focus on different tasks at the same time, directing the user's attention onto a single focal point will contribute to a reduction in cognitive load (Hogg, 2012). At the same time, an active learning environment is formed due to the fact that dynamic teaching materials and activities related to the use of these materials are controlled by students.

Cooper (1998) emphasized the need to actively participate in the teaching process while creating mental schemas. This active environment contributes to the student's attention in the lesson, cooperation and adaptation of the learning outcomes to their own cognitive structure, thus reducing extraneous load (Khalil et al., 2005). On the other hand, some researchers have stated that virtual materials help in understanding abstract concepts and reduce extraneous cognitive load. However, it has been pointed out that these materials improve the spatial skills of students with low spatial skills more than those with high spatial skills (Lee & Wong, 2014; Safadel, 2016; İbili & Sahin, 2015). In this context, other individual characteristics of students, such as thinking skills, can also be important factors in the effect of AR teaching environments on cognitive load.

Effect of AR's instructional design on cognitive load

In terms of instructional design, the intrinsic cognitive load of the student will be increased in AR systems which are difficult to use and whose instructions are complex. The cognitive effort spent on understanding these instructions will increase cognitive load in the user's working memory. However, the user's germane load may be activated in order to facilitate an understanding of the instructions and to control for cognitive load (Baumeister et al., 2017). For communication between extraneous and germane loads, it is necessary to organize working memory resources from the extraneous load towards the germane load (Paas, Van Gog & Sweller, 2010; Klepsch, Schmitz & Seufert, 2017). In order to increase germane cognitive load, it is necessary to eliminate the extraneous load that prevents the use of working memory resources. Therefore, although instructional designers have the potential to reduce both loads, they must firstly focus on strategies to reduce extraneous load (Sweller, 1999; Van Merriënboer & Ayres, 2005). In addition, the range of strategies to increase germane load has recently begun to expand (Ayres, 2006).

In virtual environments, intrinsic cognitive load will increase if the difficulty level of new learning content is high. Furthermore, the total of intrinsic and external cognitive loads may exceed working memory capacity if the presented information has an effect on extraneous cognitive load (Lee & Wong, 2014). Hsu (2017) stated that, besides the learning approach in AR learning environments, the structure, amount and degree of difficulty of the teaching materials will increase cognitive load. For this reason, it is important that interesting but irrelevant multimedia content is removed in order to reduce cognitive load, while using effective multimedia design principles instead (Mayer, 2009). Otherwise, unnecessary processing due to superfluous information will create an extraneous load for the student (Drobisz, 2017).

Mayer (2005) emphasized the importance of the preliminary preparation principle and stated that pre-knowledge, which should be possessed beforehand in relation to the teaching content, could help to decrease intrinsic cognitive load. Similarly, different researchers have demonstrated the effectiveness of this principle (Clarke, Ayres & Sweller, 2005; Van Merriënboer, Clark & Croock, 2002). Other effective ways of increasing germane load are the self-explanations of students and the application of learning methods such as stimulating students' imagination. These methods will increase both students' attentiveness in relation to the content covered in a lesson and the interaction level of the working memory elements with the existing schemas in long-term memory (Sweller, 2010). When considered from the perspective of Mayer's (2009) spatial conflict principle, the presentation of visuals or text in AR environments highlights the relationship between abstract and solid objects more clearly. Kester, Kirschner and Van Merriënboer (2004) have confirmed that the integrated presentation of learned materials improves performance. Drobisz (2017), referring to the multimedia principle of Mayer (2005), stated that the combined use of verbal and visual elements can contribute to the formation of mental schemas and the establishment of relations between these schemas.

Effect of motivational elements in AR environments on cognitive load

Problems arising from specific design approaches with regard to instructional materials can have a negative effect on mental effort. Factors such as the difficulty of a task in reflecting learners' mental effort, the resulting body of knowledge gained by the learner, the complexity of the task, as well as motivational or emotional stimuli, may also serve as examples of such effects. Indeed, the latter point has demonstrated the ability of motivation and emotion to prevent or expand the cognitive capacity of the learner (Young et al., 2014). For this reason, highly motivated students will give more effort to mental activities (Strehler, 2008). Emotional attitudes towards the learner's personal learning experiences may facilitate or prevent their learning. In this respect, AR offers the potential to increase motivation in the student, in turn producing more memorable learning experiences through expanded interaction possibilities (Chandrasekera, 2014).

The application of AR in education can reduce extraneous cognitive load by positively influencing a large number of sensory channels that lead to the working memory of the learner (Schafer & Kaufman, 2018). This is because positive attitudes can motivate students to actively spend time in the learning environment (Chandrasekera, 2014). When they interact with computers, positive attitudes can quickly motivate them to master technical skills, but negative attitudes such as anxiety can lead to difficulty in acquiring skills (Teo & Noyes, 2008). On the other hand, users' satisfaction level when using the system is affected by the perceived ease of use and perceived benefit (Ibili, Dmitry & Billingham, 2018).

Shelton and Hedley (2004) assert that the adoption of AR in the classroom motivates students to participate in task-related learning activities and encourages them to undertake a more careful examination of virtual objects using the different views afforded by the technology. Dirin and Laine (2018) emphasize that the development of intelligent mobile technologies has had the effect of increasing user expectations, while highlighting the existence of modern applications which can create emotional commitment on the part of the user. Similarly, Chandrasekera (2014) has stressed the importance of research that aims to understand human perception in AR environments, within the context of the interaction possibilities afforded by new technological developments. The factor of satisfaction that arises when interacting with AR systems is highly effective in maintaining the behavior and creating a positive attitude necessary for usage. The design of personalized AR applications and user interfaces and the AR hardware employed for a given task are important factors in ensuring effective user satisfaction (Xue, Sharma & Wild, 2018). Debué and Leemput (2014) demonstrated a negative relationship between extraneous load and germane load, as well as a linear relationship between extraneous load and intrinsic load. They observed a negative correlation between performance and intrinsic and extraneous load, but were not able to detect any association between performance and germane load.

Effect of interaction interfaces on cognitive load

Although research has been conducted for a long time on AR, there is still a need to develop new intuitive and interactive interfaces. Issues in interaction may arise, for instance, when inexperienced users are unable to manage the computer connection when working in marker-based environments, or when the ergonomic use of an environment may not be possible due to the limited display area of the camera (Lee, Billingham & Woo, 2010; Ferreira, 2014).

Turk and Robertson (2000) define natural user interfaces as systems that allow for interaction between the user and a computer system through various media (kinetic, body language, aural, visual, haptic etc.), similar to user interaction with real-world objects. In this way, the user may experience interaction between themselves, their environment and the system through naturally interactive media while performing a certain task (Wigdor & Wixon, 2011). Natural user interfaces should be easy to use, intuitive and entertaining, but without being intrusive; moreover, the user should not need to learn how to operate any external device or perform any additional commands or procedures for interaction with the system (Kaptelinin & Nardi, 2012). Schafer and Kaufman (2018) emphasize that ease of use is an important factor in eliminating cognitive load, which has led researchers to develop intelligent and interactive AR interface designs. However, researchers also point out that natural interaction interfaces should be designed to accurately identify user requests during interaction and to provide the user with intuitive means of interaction with low cognitive effort. On the other hand, the development of natural interaction interfaces in AR allows a designer to freely manipulate their design, allowing for epistemic actions and thus reducing the cognitive load of the user as well as of the designer (Chandrasekera, 2014). In addition, interactive AR interfaces increase the interaction between students as well as facilitate effective interaction between the user and the materials. Baraldi et al. (2009) stated that the aim of designing natural interaction interfaces is to design complementary environments by transferring the communication language that people have established with each other to technological applications.

Some researchers have begun to explore the potential of interaction within AR environments through the use of gesture. Chessa and Noceti (2017) reveal that user interaction with virtual content involving human hand gestures has resulted in more successful performance indicators (such as speed, error rate, the natural quality of interaction), compared to a virtual hand avatar. Comparative studies focusing on interaction methods that use marker and hand movements in AR environments reveal that hand movements tend to shape a more natural interaction perception than interaction with a marker, thereby offering considerable potential for viewing 3D objects from multiple perspectives (Al Agha & Rasheed, 2014). Bai (2016) states that, while interaction with 3D motion-based free-hand movements without the use of markers is more intuitive and natural than 2D touch-based interaction with depth perception, this may create limitations for 3D motion-based interaction.

The effectiveness of guided teaching procedures to reduce cognitive load, especially for novice students, has been demonstrated previously (Paas, Van Gog & Sweller, 2010; Kirschner, Sweller & Clark, 2006). Dirin and Laine (2018) found that virtual avatars directing the user with an AR-supported virtual campus tour showed the potential of AR to reduce cognitive load in terms of guided teaching procedures. Research has also been conducted on how to use this technology more efficiently, against the emergence of new hardware or new interaction features to support AR applications (Chandrasekera, 2014; Dieck & Jung, 2015). This implies that traditional task analysis methods do not adequately respond to user needs or may indeed ignore user needs altogether. As such, the cognitive or affective characteristics of the user should be taken into consideration during the design and implementation of interactive systems (Arvanitis et al., 2011).

DISCUSSION AND CONCLUSION

In this study, the relationship between the potential and limitations of AR learning environments and cognitive load was investigated. Within the scope of the research, the potential and limitations of AR learning environments, as revealed in previous systematic literature reviews, were

firstly determined. Then, the relationship between the potential and limitations of AR learning environments and cognitive load components were discussed.

Cognitive load is an important factor to consider when designing effective instructions. A high level of cognitive load should be avoided when planning learning activities. The factor of cognitive load should be taken into consideration in the design of teaching activities and materials that are supported by instructional technologies. Cognitive activities that lack a strong relationship with learning objectives or whose interface systems are not well designed may have a negative effect on teaching by contributing to increased cognitive load. In this research, the relationship between cognitive load and AR learning tools, which possess strong instructional potential in terms of blended real-virtual interaction possibilities, was investigated. The relationship between the subcomponents of cognitive load were initially presented, while that between these subcomponents and AR teaching environments was compiled in terms of pedagogical theory, instructional design, learner motivation factors and the purposes of user interaction.

From the pedagogical point of view, AR teaching materials could serve as symbolic representations between abstract and concrete concepts. Thus, such materials may facilitate teaching by extending learning content from the abstract to the concrete, thereby reducing the cognitive load of the user. With regard to AR materials, the attention of the student can be directed towards a specific target point, meaning that mental complexity and working memory load can be alleviated. The technical capabilities afforded by AR, such as the visualization of teaching materials using all manner of 3D perspectives, could develop spatial skills and contribute to schema acquisition for learners. The application of AR technologies has previously demonstrated the potential to strengthen the interaction between students, teachers and teaching materials, while encouraging the active participation of students on courses and reducing foreign cognitive load. There is sufficient evidence to suggest that AR-based instructional system design, which results in difficult-to-use interfaces and whose instructions are complex, could increase students' internal cognitive load. In addition, interesting but irrelevant multimedia content, which is at times present in such interfaces, can serve to increase students' extraneous cognitive and working memory loads. In this context, cognitive load can be reduced by using effective multimedia design principles, such as Mayer's (2005) pre-training principle, multimedia design principle and spatial contiguity principle. Teaching methods such as self-explanations, imaginative thinking and guided teaching procedures can be used to reduce foreign cognitive load. In this way, students may devote their attention to the lesson, thus reducing their internal cognitive load. This might occur when the interaction of the diagrams in the student's working memory with the diagrams in their long-term memory is increased. Problems arising from the design of instructional materials also imply there are negative effects on factors such as motivation and mental effort. Motivation and emotion may be decisive factors with regard to learner cognition, wielding the power to either interfere with or increase the cognitive capacity of the learner. In this respect, AR has the potential to enhance student motivation, simplify the learning process and create more memorable learning experiences through increased interaction possibilities. On the other hand, easy-to-use, intuitive, entertaining and non-intrusive natural interaction interfaces can enable the user to complete tasks with little cognitive effort. Thus, the level of interaction between students and instructional materials, as well as the level of interaction with other students and teachers, may also be increased. In addition, employing natural interaction interfaces can enable the active participation of the student and direct their attention towards the lesson, while reducing foreign cognitive load.

This research, while examining the relationship between AR teaching environments and the subcomponents of cognitive load, is limited to the pedagogical, instructional design-related, motivational and interactional dimensions of AR environments. For these reasons, future studies should examine the relationship between AR environments and cognitive load in terms of these different dimensions, while discussing other teaching methods or instructional design principles that may be effective in reducing cognitive load. It is hoped that the results of this research can be of importance to AR developers and instructional designers by providing a theoretical background for controlling or reducing cognitive load.

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