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Augmented Reality in Support of Physics Laboratory Activities: A Systematic Literature Review

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Learning physics is considered a challenge for many students who have negative attitudes towards physics. The limited learning tools and laboratory-based learning approaches has not led students to the expected scientific process. Augmented reality (AR) can be a promising tool to overcome this challenge. This paper discusses the potential of AR in solving problems associated with laboratory-based physics learning. A systematic literature review is conducted, as a comprehensive analysis of the potential use of AR in laboratory-based physics learning. The study shows that the use of AR may possibly solve laboratory-based physics learning problems that have been experienced by physics instructors.

Keywords: *Augmented Reality, Laboratory, Physics Learning.*

Introduction

Many students have negative attitudes towards physics. For this reason, effective teaching of physics must encourage learning by developing positive approaches in students (Sarı & Güven, 2013). Physics can be challenging to understand, if only learnt through imagination. Therefore, laboratories play an important role in learning science, especially physics. Laboratory-based learning is not only able to improve understanding of science concepts, but it also teaches students how to use various instruments, conduct data analysis, and assist in the development of collaborative skills (Leung, Hashemi Pour, Reynolds & Jerzak., 2017).

It is hard to consider learning to do science or learning about science, including physics, without doing laboratory experiments or fieldwork (Musik, 2017). Expensive or inadequate laboratory equipment, equipment errors, difficulties in simulating certain experimental conditions (Cai et al., 2017; Leung et al., 2017) are all problems found to hinder laboratory-based learning in physics. Because of the high cost, some educators may question the effectiveness of laboratory-based learning and whether the expenses outweigh the potential learning outcomes.

An essential part of laboratory-based learning is the activity manual and practical preparation. It is critical for the readiness of the educators and the students to carry out the laboratory-based learning process. An activity manual and practical preparation are essential for many reasons including, indicating how the students are involved in the learning, how the students acquire skills, and how the students acquire knowledge (Van De Heyde & Siebrits, 2019).

In recent years, with advancing technology and the development of technological equipment in both the laboratory and in the classroom, the effectiveness of teaching physics has improved (Sunal, Wright, & Bland, 2006). The use of technology in learning science, including physics, can facilitate the process of describing existing phenomena, and this is better than the traditional learning processes that does not involve technology (Arici et al., 2019). The advance in the use of technology in learning science means that teachers now need to be capable of integrating the technology into physics learning, especially in laboratory-based education (Aththibby et al., 2019).

At present, AR technology has emerged in fields such as mathematics and science, because it enhances student activity and brings them into individual learning environments (Arici et al., 2019). AR can be integrated with mobile learning and game-based learning. Scientists have included techniques such as voice and motion recognition, geolocation, compass, fast response codes, cameras on handheld devices, mini projectors, AR mobile browsers, etc. The result of AR in learning is active learning rather than passive non-interactive learning. Like simulations, AR has great potential to motivate students with games. Because of these attractive features, researchers increasingly recognize AR technology as a potentially useful method of improving the science learning process (Chiang, Yang, & Hwang, 2014; Chang, Wu, & Hsu, 2013; Wu, Lee, Chang, & Liang, 2013; Sollervall, 2012).

For this reason, the purpose of this paper is to present a study related to the potential use of AR in supporting laboratory-based physics learning activities. To do this, the authors conducted a Systematic Literature Review (SLR) which included a rigorous review of the literature assessing the reproducibility, scalability and objectivity of all research.

Methods

A SLR can help provide answers to specific research questions (Hussain et al., 2019). Figure 1 shows the stages in a SLR. To best present our SLR findings, we have summarised the steps carried out in each stage of the SLR, then presented our findings for that phase.

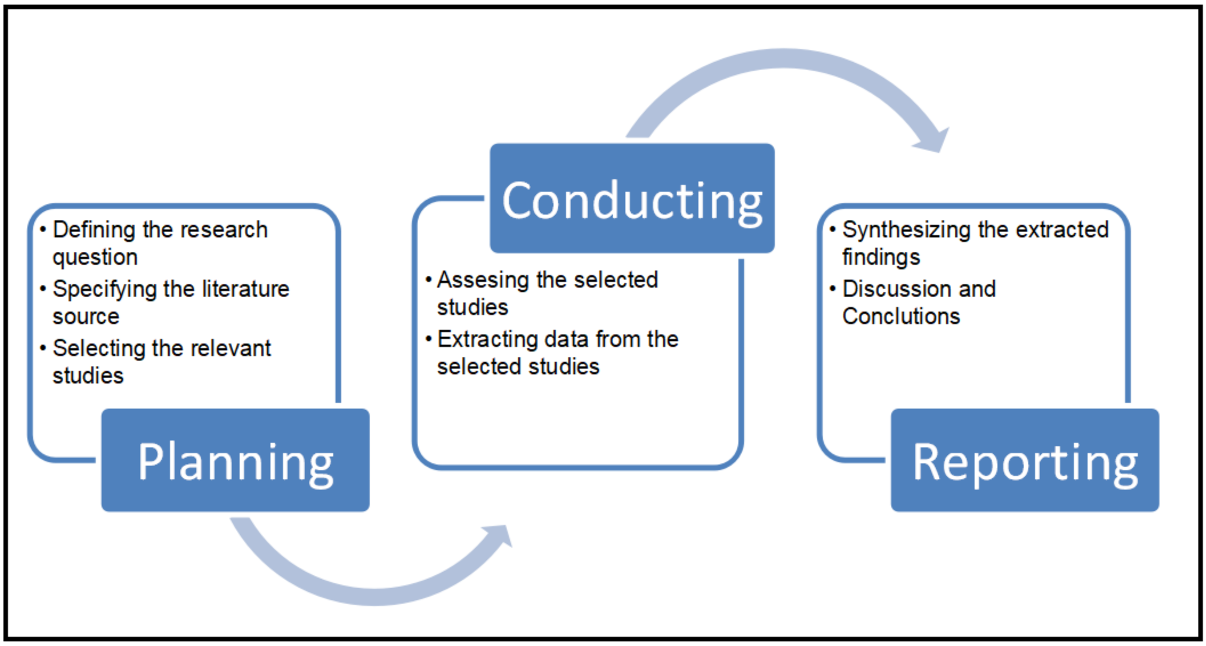

Figure 1. Stages in a SLR

Step 1: SLR Planning

The best evidence from the existing literature was gathered. The SLR process provides the best techniques to use for collecting and analysing the evidence from primary studies. This included addressing the importance of the various methods used, for each research question. The studies were chosen based on the quality of the title, abstract, and the conclusions. The results of this phase of the SLR planning illustrated that there are currenlty no other SLRs published that have the same indepth coverage of the research in AR in education.

Many studies have reported the advantages, limitations, challenges and effectiveness of AR in education. However, further research was needed to get a general picture of the progress and real impact of the use of AR in the learning process, especially laboratory-based physics learning. We have addressed this gap in the research by asking the questions and objectives displayed in table 1 when conducting our SLR.

The studies used in our SLR were obtained by searching through Elsevier, ProQuest, Taylor and Francis pages, and Google Scholar. As previously mentioned, the first search was evaluated by assessing the title, abstract, and conclusion of each study. The secondary search was complete by searching and tracking the bibliographies of the studies, to further answer our research questions and objectives.

Step 2: SLR Conducting

In this stage of the SLR, all articles collected were analysed and selected according to how they related to our research questions. To answer the research questions, we set a selection criteria:

a. Research must focus on the use of AR in supporting practicum modules in science learning. Published research that did not address this criteria were excluded.
b. Research must be empirical, reporting data generated from actual observations or experiments. Articles based on personal opinion or anecdotal experience were excluded. The theoretical and conceptual parts were also excluded from the analysis but were carefully reviewed to strengthen our background knowledge and to broaden the theoretical foundation.
c. Research must be published in a peer-reviewed academic journal, in English, between 2008 and 2020. Papers published in non-peer-reviewed, non-English-language journals, or outside this time frame were excluded.

Step 3: SLR Reporting

This section discusses the answers to research questions, and the assessment or answers to questions raised are based on the analysis of the selected article. Facts from each research question extracted after analysis of selected studies. The results of studies based on articles that have been synthesized are expected to be able to give an idea of the potential use of AR in physics laboratory activities both in terms of weaknesses and advantages.

Results and Discussion

Augmented Reality Character

The first research question considered following the SLR wasto explore the key characteristics of AR in learning. Some researchers have proposed different definitions of AR. For example, El Sayed, Zayed, & Sharawy (2011) assert that AR allows the addition of information that is lost in real life, by adding virtual objects to real scenes. Supporting this definition, Chen & Tsai (2012) show that AR makes it possible to interact with integrated 2D or 3D virtual objects in a real-world environment. Cuendet et al. (2013) state that AR refers to technology that projects digital material to real-world objects. This definition by Cuendet et al. (2013) is based on one of the AR features that is to superimpose virtual information on real objects.

Another perspective of AR has been adopted in the study of Wojciechowski & Cellary (2013). The AR enable merging virtual objects with the view of real objects, resulting inaugmented reality environments. Sırakaya & Sırakaya (2020) suggest the main feature of AR is its support for learning outside of the classroom. Along with the main features of AR that are strengths, AR also has challenges or weaknesses, as shown in table 2.

The strengths, challenges and weaknesses of AR influence both the AR-based education and also the research identifying the benifets or usefulness of AR-based education. These challenges or weaknesses are generally related to technical problems (Rabbi & Ullah, 2013). Internet connectivity, the low sensibility of the markers used, and the stability of the programs being run are a technical challenge in carrying out both AR-based learning and research on the benifts of AR-based leaning. These challenges are especially seen in the use of AR-based learning in laboratory-based learning activities guidelines. Teacher resistance to AR and the need for long periods to design and develop content are also another challenge in implementing AR in learning (Gavish et al., 2015).

Benefits of Augmented Reality in Education

The second research question of the SLR was to explore the benefits of using AR in education. The results of the SLR suggested that there is a place for AR in education to support the learning and teaching process. The benefits of using AR in learning are see in table 3.

As presented in table 3, the benefits obtained from the use of AR in learning include AR-positive effect on attitudes and learning outcomes, the ability to visualize concepts, increase knowledge and skills, and increase learning motivation. These findings reinforce the results of a study conducted by Martin-Gonzalez, Chi-Poot, and Uc-Cetina (2016), which concludes that the use of AR makes learning activities easier and is also able to increase the intensity of learning and teaching activities.

The benefit of AR in education is also backed by research showing the ability of students to examine 3D objects from a variety of different perspectives to improve their understanding (Chen, Chi, Hung, & Kang, 2011). It has also been suggested that AR-based learning activities not only enhance students 'knowledge construction, but also involve learners' experiences in the learning process (Chiang, Yang, & Hwang, 2014; Sommerauer & Müller, 2014; Ibáñez, Di Serio, Villarán, & Kloos, 2014).

Augmented Reality in Laboratory-Based Learning

The third research question from the SLR was to assess the ability of AR to strengthening laboratory-based learning. In the physics laboratory, students are expected to conduct scientific experiments using a variety of methods and use observational skills, build and test hypotheses, experiment, and make conclusions and actions based on what they find. The steps for understanding experimental data are to classify, to build significant relationships, and present them to interested parties. The ability to draw and understand graphics is essential because transforming recorded data into graphs and identifying relationships between variables, as a result of graph analysis, are essential steps in reaching the end of the experiment.

The results of the SLR of studies investigating the use of AR in laboratory-based learning can be seen in table 4. Based on the search results, it is shown that AR can increase interest in practicum activities and help students to gain better laboratory skills. The use of AR in physics practicums is proven to be able to increase students' understanding of concepts and improve their attitude, motivation and attention to laboratory-based learning. This AR potential can strengthen mobile laboratory-based learning (Akçayır et al., 2016), and also its ability to support inquiry-based activities (Chen et al. 2012).

Conclusion

This SLR aimed at providing an overview of the potential use of AR in laboratory-based physics learning. It was found that AR is able to support both learning outside the classroom and the teaching process. In addition, AR class-based and laboratory-based learning also helps the practitioner or educator gain better laboratory skills and improve conceptual understanding. In addition to the advantages and potentials AR-based learning also had challenges, including difficulty with internet connectivity, low sensibility of the markers used and problems with the stability of the programs used. From the overal findings of the SLR, it can be concluded that the use of AR in the process of learning science, especially physics, is an important research topic requiring further investigation. The summary of the research in this SLR can guide AR studies in laboratory-based learning in subsequent research.

Table 1. Research questions and objectives

	Research Questions	Research Objectives
1	Characteristics (Strengths and Weaknesses) of AR	Know the advantages and disadvantages of using AR to optimise the use of AR in learning.
2	Benefits of AR in Learning activities	Understanding the effectiveness of using AR in achieving learning goals.
3	The potential of AR in laboratory-based learning	Analysing and measuring AR's ability to strengthen laboratory-based education.

Table 2. Weaknesses of AR in learning

Sample research	Results
Cai et al. (2017);	AR systems are not always stable.
Wu et al. (2013).	The use of various devices for AR applications can create more technical problems
Akçayır & Akçayır (2017)	Difficult design
Cheng & Tsai, (2013).	The low sensibility of the markers used
Akçayır & Akçayır, (2017); Wu et al., (2013).	The existence of internet network disruption also disrupts the system being run.

Table 3. Benefits of AR in learning activities

Sample research	Results
Cheng (2017).	The use of AR in the future to explore the role of cognitive load in the learning process.
Cai et al. (2017)	The use of AR in learning physics can improve learning attitudes and learning outcomes
El Sayed et al. (2011)	AR helps students to enhance their knowledge and skills
Barsom et al. (2016).	AR provides flexibility in learning by offering interactive environments that can be adapted to real-world environments
Di Serio et al. (2013); Wu et al., (2013); Georgiou & Kyza (2018); Ibáñez et al., (2014)	AR helps students understand abstract concepts.
Mumtaz et al. (2017); Chang & Hwang (2018); Cheng (2018); Georgiou & Kyza (2018).	AR helps increase student learning motivation.

Table 4. Effects of AR in laboratory-based learning

Sample research	Results
Cai et al. (2014)	The use of AR in practicum instructions can increase interest in practical activities
Akçayır et al. (2016).	Provision of AR components (videos, animations, images, etc.) improves laboratory skills.
Cai et al. (2014)	The use of AR in physics practicums shows improvements in students' attitudes, motivation, and attention in learning.
Mumtaz et al. (2017)	The use of AR can improve understanding of concepts through the learning experiences provided.

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