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A Review of Augmented Reality in Physics Education and physics laboratory experiments (Applications, Advantages, Challenges)

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Abstract

Augmented reality (AR) is one of the latest technologies that have demonstrated to be an efficient tool to improve pedagogical techniques, it have the potential to transform physics education by making challenging concepts visible and accessible to everyone.

This study presents a review of the literature on the use of augmented reality AR technology to support physics education as a developed technical learning environment, and evaluate it to determine the effectiveness of it in physics education. It synthesizes a set of 102 publications from 2000 to 2021.There were articles found using the keywords "Augmented Reality and Physics", " Augmented Reality and Physics, Augmented Reality and Physics Education, Augmented Reality and Physics Laboratory, Physics education development, Physics Education Motivation". A content analysis is used to investigate the characteristics, advantages, and applications of augmented reality in in the context of physics concepts and physics laboratory experiments. The findings reveal an increase in the number of AR studies in physics education during the last years, and the Most of the studies reviewed emphasize a positive effects of learning with (AR) in various instructional ways, where is the augmented reality learning components is foster learning by permits the learners to observe the real world with augmented virtual elements.

Thus, AR provides important advantages in fostering students' conceptual understanding and good learning outcomes, motivation, performance, thinking level, technical skills, and the expertise. In addition, its role in pedagogical contributions and improve the learners interactions. However, few studies have pointed out some challenges to the use of augmented reality technology in physics education. Some noted challenges imposed by AR are usability issues and technical problems. In addition, current gaps in AR research and needs in the field are identified.

A number of suggestions for future research arose through this review for previous studies, it is suggested that augmented reality should be used in several subjects of physics which are difficult to comprehend. and AR experiences should complement traditional curriculum material. More studies related to the development and usability of AR applications are needed. learners' opinions about usability and their suggested solutions to problems which they encountered should be more deeply explored. Additional research could be directed toward student satisfaction, motivation, interactions, and student engagement to better understand the advantages of AR in educational settings. also, the conditions relating to the problem of cognitive overload in AR technology applications should be researched (topic, age group, interface characteristics, etc.). Future studies on integrating augmented reality technology into smartphones applications and electronic gaming market to simulate physical concepts and experiments. Determine the best tools-based AR application (tablet-based AR, smartglasses, smartphones, etc.).

Keywords: Augmented Reality and Physics, Augmented Reality and Physics Education, Augmented Reality and Physics Laboratory, Physics education development, Physics Education Motivation

1. Introduction

Education plays an essential role in a nation advancement. It is important that a learning process influences the improvement of education quality and Learning Outcomes, and some foundations that support the learning process are curriculum, teaching programs, learning approaches, educators' quality, learning materials, learning strategies, and learning resources. The society in which the current generation is characterized by technological progress, scientific innovation and globalization differs significantly from the society previous generations grew up in. Now they use laptops and smartphones to connect with friends and family, they access information online, use several media, participate in activities in the virtual environment, express and support their opinions. So it is spreading right now the use of technology in learning process; where traditional teaching began to shift to online learning as open Online Courses on internet, social media (Youtube, Facebook, WhatsApp, Line, Zoom, Edmodo, etc.), virtual learning, and e-learning **(Suprapto and Pai, 2015)**. The trend of literacy was also shifted from traditional literacy to digital literacy, such as from paper book to e-book **(Adam and Suprapto, 2019)**. Consequently, the use of applications and software is necessary to meet the demands of the education.

In education field, the oldest way of teaching are screen or blackboard, also books are one of the students' main learning sources. The books actually are available. But, since some research results found that students they may have difficulty in understanding a lot of concepts in their study in scientific material. It make great potential and opportunities and has good prospects in science education to be applied in learning science, such as biology, physics and chemistry, especially physics **(Nielsen et al., 2016, Chen et al., 2017, Techakosit and Nilsook, 2016, Elmqaddem, 2019, Nuanmeesri, 2018, Sannikov et al., 2015, Ozdamli and Hursen, 2017, Nasongkhla et al., 2019, Nandyansah et al., 2019, Techakosit and Nilsook, 2016)**. Some circumstances may hinder traditional teaching methods. Such as the lack of availability of the required educational material completely, or the presence of obstacles in pursuing direct education in schools and universities; Like the Corona pandemic (19-COVID) that occurred in 2020, this global epidemic that causes impediment to face education in most countries of the world. So students need other educational materials which can enrich their knowledge mastery and become the complementary of student textbooks. The studies see that the development of technology is very supportive of learning practices, the utilization of its technology can be seen from the existence of computer-based learning **(Kukkonen et al., 2016)**. web-based learning **(Yi et al., 2018)**, mobile app-based learning **(Ahmed et al., 2018)**, and virtual-augmented reality technology-based learning **(Papanastasiou et al., 2018)**. Moreover, the visualization technologies developed in the last years led to the unification of the virtual and real environments by enhancing the experience within the real/virtual environment with elements specific to the opposite one, thus Hence, the advantages of the real and virtual worlds can be combined by performing practical activities and experiments in real environment enhanced with virtual elements **(Milgram and Kishino, 1994)**.

What is the augmented reality (AR) technology?

Augmented reality (AR) technology is attributed to former Boeing researcher Tom Caudill, who is believed to have coined the term in 1990. Some researchers in educational technology and computer sciences have defined AR based on its features or characteristics. For example, Azuma (1997) defined AR as a system that fulfills three basic features: real and virtual combination, people working interactively in real time, and accurate 3D registration of virtual and real objects, which can be viewed and interacted with in real time. **(Klopfer and Squire, 2008)** indicated that the term AR should not be defined restrictedly, This term could be applied to any technology that blends real and virtual information in a meaningful way. AR could be broadly defined as “a situation in which a real world context is dynamically overlaid with coherent location or context sensitive virtual information” **(Azuma, 1997, Lee, 2011, Klopfer and Squire, 2008)**. Through this technology, real environments are enriched with virtual objects or information generated by computer-based technologies, this mean that Augmented Reality only adds or complements reality, it is an effort to combine the real world and virtual world created through a computer **(Carmigniani et al., 2011)**. AR could be created and implemented by varied technologies, such as desktop computers, handheld devices, head-mounted displays and so on **(Dunleavy et al., 2009)**. AR is usually divided into two types; The first is position-based and the second is image-based. Position-based Augmented Reality is based on physical location. The 3- dimensional text, graphics, sound, video and animation models presented depend on GPS coordinates or compass measurements. This type of image-based Augmented Reality uses a camera on a smartphone or tablet to scan QR codes or 2D images; this allows the emergence of 3-dimensional animation above the image **(Majgaard et al., 2017)**.

The technology of augmented reality (AR) has grown exponentially in the past decade **(Nadi et al., 2020)** and is now being applied widely in the field of education as well as it has been actively researched since the 2000s **(Schmalstieg and ¨ollerer, 2016)**, and many research results have been derived which show the advantages of AR technology in education **(Klopfer and Sheldon, 2010, Santos et al., 2014, Radu, 2014)**. The results of previous studies provide concrete evidences for the usability of AR in teaching physics subjects **(Bujak et al., 2013, Winkler et al., 2002, Cai et al., 2013, Ibanez et al., 2017, Wu et al., 2013)**. Teaching materials which are equipped with AR can facilitate an interactive learning atmosphere between students and the learning environment, and can help students in describing and visualizing the concepts of science and physics phenomena **(Abdüsselam and Karal, 2012)**. Besides, the use of AR technology in the form of pictures and videos in learning activities can enable learning materials to be more flexible, interesting and interactive, so that it can increase students' activeness and learning motivation, thus enhancing the learning experience of students, in this way it will be easier for students to build their knowledge. Thus, learning environments will be funnier, interactively, effectively and also powerful **(Nincarean et al., 2013 Ibanez et al., 2014, Liu et al., 2007, Kirkley et al., 2005, Zagoranski and Divjak, 2003, Alouf and Bentley, 2003)**. As a result, the application of AR technology in the learning process should be a trend in learning physics at this time. , especially in difficult topics which need a useful technology to understand **(Chen et al., 2017)**.

Physics is one of the academic disciplines that involves the analysis of nature and understand it. It also has played an important role in the development of the new technology **(Milgram and Kishino, 1994)**. One of the roles of computers technology in the teaching of physics is to support the building of knowledge and retention practice **(Serway and Beichner, 2002)**. In addition, physics can provide more realistic expressions based on simulation techniques by AR, which enable students to gain high achievement.

Researchers have developed systems that visualize invisible phenomena in the field of physics **(Yau et al., 2020, Kapp et al., 2019, Aoki, 2018, Aoki et al., 2018, Strzys et al., 2017, Hockett and Ingleby, 2016, Kuhn et al., 2016, Sandor et al., 2015, Santos et al., 2014)**, numerous studies have been carried out to express motion in the real world through physics-based simulation, such as free fall, parabolic motion, and comparison of changes according to object characteristics **(Jonassen et al., 1999)**. AR can be used to improve learning on kinematics properties in physics **(Nak-Jun et al., 2019)** , For example, in mathematics, physics, and engineering, Euclidean vectors are geometric objects that characterize physical quantities having magnitude and direction (e.g. force, velocity, acceleration), contrary to scalar quantities that have no direction (e.g. time, temperature, displacement).

Physics education is built on practical experience and must be tested through experiments in laboratories that concepts are formulated based on facts and data's results **(Duarte et al., 2005)**, developing scientific attitudes, cognitive aspects, affective aspects, psychomotor aspects and skills for students, , and Creative thinking skills and problem-solving skills in them **)Zaghloul, 2001)**. In physics education, the best application of augmented reality is in laboratories and physical experiments, and the reason is that there are several challenges inherent to the education of physics laboratories; such as expensive or insufficient laboratory equipment, equipment error, difficulty in simulating certain experimental conditions specially in hard conditions as COVID-19 pandemic that began in 2020 and which affected the world, especially the education sector, which didn't allow students present in their education places for a long time. Augmented reality (AR) can be a promising approach to address as these challenges into the world of education, especially in the physics education laboratory **(Chao et al., 2016, Cindi Ratna Putri et al., 2021)**, The researchers also stated that Physical phenomena can pack with AR technology in the form of animation, video, and even virtual laboratory in experiment activities **(Nadelson et al., 2014)**; that can improve the development of student laboratory skills and it can help them complete laboratory activities in a shorter time so that they have more time to discuss the results of the experiment, so can make time-efficient **(Duban, 2019, Akçayır and Pektas, 2016)**.

2.Significance Of The Study

This review aims to evaluate the AR technology application which have been used to deliver developed technical learning environment in physics education field. The purpose is reviewing of research articles from 2000 till 2021 regarding the usage of augmented reality AR technology in physics education and how to improve the teaching methods it, From this review of the previous studies we show the advantages of AR, its limitations, uses, challenges, its scope in the physics education laboratory field. we see that how AR helps the students for better understanding the events of the physics environment and make able to have more better realistic application.

3.Objectives of The Study

For this review, we selected scientific articles on the physics education by uses of AR, we applied content analysis where we used"Augmented Reality and Physics", "Augmented Reality and Physics Education" an "Augmented Reality and Physics Laboratory". Google Scholar and open access journals are referred as primary databases to search the literature. Previous studies have shown that AR has many advantages in education; however, few Focuses on the challenges and solutions to them, such as the effect of AR on learners' self-efficacy and conceptions of learning.

There are Several results has been adopted it from previous studies to use AR to knowledge the effectiveness of it in teaching physics ; (A) main content related to Effects of learning physics using Augmented Reality (advantages), (B) focused on the effectiveness of AR apps in teaching students the physics experiments, (C) focused on the challenges of using augmented reality in physics education, based on the previous studies whish which we reviewed.

Based on the results for retrieved papers are from 2000 till 2021. Researchers have striven to apply AR to learn physics subjects in schools, Higher Education, universities and Higher Technical Educational Institutions, and to adopt it into augmented books and student guides.

4. Results and Discussions

The reviewed studies indicated many results for the use of augmented reality in teaching physics, and the results included the advantages in learning outcomes as well as the challenges faced by the application of this modern technology in physics education.

4.1. Effects of learning physics using Augmented Reality (advantages)

Recent studies highlight the benefits of AR in the context of physics concepts and laboratory experiments in various instructional scenarios concerning knowledge acquisition and cognitive load compared to traditional settings, particularly in the context of physics concepts and laboratory experiments, so the use of augmented reality (AR) in physics learning has become of increasing interest to researchers. The most of the studies reported that using AR technology in physics education leads to add realistically to many subjects, and it has many good learning outcomes, pedagogical contributions, and improve the interactions between (students together, students-material, and students-teacher) **(Ibanez et al., 2014, Billinghurst and Dünser, 2012, Thees et al., 2020, Cai et al., 2017)**. Particularly that Studying physics, requires reasoning skills and thinking to understand the concepts. After reviewing previous studies, advantages of AR in physics education were arranged into three categories:

1. Learning achievement and learning outcome:

Most of the studies suggest that AR learning environments are effective in physics education and leads to "enhancement of learning achievement" in educational settings. Our review findings indicate that AR can "enhance learning motivation," "help students to understand," "enhance positive attitude," and "enhance satisfaction." According to **(Chiang et al. 2014a)** AR technology components such as videos and 3D images and adding visual and textual components to the learning process can help students to more fully understand their learning content, it provides immediate and relevant information, as well as guidance to the students **(Chiang et al., 2014, Yoon et al., 2012)**.

This method is also perceived by students as more satisfying than classroom lessons **(Chen and Tsai, 2012)**. In learning activities integrated with AR, the students were observed to participate more, appeared more comfortable, were able to answer questions related to the subject more easily, and exhibited higher academic achievement levels in physics (**Bakri, et al.,2019, Mustafa and Karl, 2020, Mustafa and Meric, 2019)**.

AR technology could bring positive effect in the educational context in physics. For example, **(Cai et al. 2021)** developed specialized AR teaching tool and applied it in physics education, its results showed that the AR assisted experiments can significantly enhance self-efficacy and conceptions of learning physics for students. it stated that the students in the AR group scored significantly higher than those of the another groups in terms of Conceptual understanding, Higher-order cognitive skills, Practical work and Social Communication **(Cai et al., 2021)**. In addition, the researchers suggested that AR learning environments should be used in subjects of physics which are difficult to comprehend such as magnetism, atomic model, and visual learning, because it enable students to understand it much better, can take students' attention, that affects their academic success in a positive way. According to obtained results that using augmented reality in teaching magnetism has benefits by providing the visualization and it helps the student for better understanding the events of the environment, such as magnetic field dimensions, direction finding, and especially the right-hand rule of magnetism **(Mustafa and Karl, 2020, Wang et al., 2018, Mustafa, 2014, Buesing and Cook, 2013 ,Macedo et al., 2012)**.

According to **(Iulian Radu & Bertrand Schneider, 2019)** The educational AR representations is beneficial for increasing the ability to learn concepts in physics. its more effective in developing understanding of the invisible structures of magnetic fields, understanding the connection between electrical currents and magnetic fields, transferring knowledge on how to construct electromagnets, and finishing the task on time. Users could concurrently observe the direction of electricity while watching magnetic field shapes, it allows learners to easily keep track of relevant information while exploring the dynamic nature of relationships between important variables. according to the results, Augmented reality has the power to increase motivation, and more effective at changing student self efficacy towards physics. participants who used the system with AR educational representations, they felt a deeper sense of aesthetics and involvement **(Corey and Joseph, 2020, Iulian and Bertrand, 2019)**.

Also, one of abstract physics concepts representative in the use of augmented reality in physics learning is the atomic model. One of recent studies of the outcomes of the PicsAR (Physics Augmented Reality) research project that is focusing on the evaluation of students' abstract thinking skills was **(Nadi et al., 2020)**, the results indicated the process of developing AR in atomic model fulfill the criteria of product quality: validity, practicality, and effectiveness, performing of students' abstract thinking skills increased in the combination of good and very good categories of all reasoning categories, therefore, the recommendation of this study was another abstract physics concepts should address the use of AR as a media for learning **(Nadi et al., 2020)**.

One of modern studies which investigated using of AR by applying it on the effects of Problem Based Learning (PBL) on learning achievement and attitude towards physics subjects was **(Mustafa Fidan & Meric Tuncel , 2019)**, The experimental results indicated that integrating AR into PBL activities both increased students' learning achievement and promoted their positive attitudes towards physics subjects. This technology contributed to students' long-term retention of the concepts in the field of physics. AR applications were more useful, realistic, and interesting for students' learning; helped them to understand and analyses the problem scenarios **(Mustafa and Meric, 2019)**.

2. Pedagogical contribution

According to the results our review, the pedagogical contributions of AR were clear, it bring positive effect in the pedagogical with educational context in physics courses such as the self- efficacy, self-confidence, also it bring positive effect on learning performance, attitudes and motivations, where are Students which have increase self-confidence they appear more comfortable and exhibit higher academic achievement levels in physics, one of the positive effects also that AR allows the teacher to assign responsibility to the students, and it allows students to make their own decisions. These contributions enhance student engagement **(Cai, 2021, Bakri et al.,2019, Mustafa and Meric, 2019, Apittha, 2019)**.

The augmented reality as new technology or new visualization techniques has been shown to be highly motivational for users regardless of any educational content, this make it a potential and effective tool for activating students' positive emotions, it due to that the participants who use the system with AR educational representations, they felt a deeper sense of aesthetics and involvement, Furthermore, Some researchers reported that the most prominent contributions of AR is enhancing enjoyment which make boring instruction more entertaining, also it is raising the level of engagement **(Iulian and Bertrand, 2019, Angel Chi-Poot and Anabel Martin-Gonzalez, 2014, Ibanez, 2014, Di et al., 2013)**.

In another studies, such as **(Cai et al., 2013)** showed that AR application which was created for a convex imaging experiment in a physics course was an effective tool in enhancing the students' attitude, motivation, and attention (Cai, 2013). Another study showed that the augmented reality approach was more effective in promoting students' knowledge of electromagnetic concepts and phenomena. with more concentration, sense of control, clearer direct feedback, and autotelic experience (Thees et al., 2020). (Cai et al., 2017) designed an interactive application that supported the AR software for teaching magnetic fields or magnetic induction, The results of their study indicated that it could promote students' learning outcomes and can stimulates students' motivation to learn physics more deeply, this brings students into a more realistic experimental environment, so students pay more attention to the experiment itself and the inquiry process, students appeared relaxed, happy and playful as they learned through play, so this improve their learning motivation **(Cai et al., 2017)**. This finding is in accordance with some previous studies, where **(Chiang et al., 2014)**.

3. Interaction and Engagement

Students interaction and engagement is a critical component of learning. And modern technologies especially AR technology have a good effects on it. that related to learners' interactions (student-student, student-material, and student-teacher) were grouped under the interaction category. According to reviewed studies, AR learning environment provides students with natural interaction, this brings students into a more realistic experimental environment, effective at motivation students and fostering collaboration **(Cai et al., 2017, Cai et al., 2021,Iulian and Bertrand, 2019)**. In addition, AR technology promotes more interaction among students and more between students and the learning material – thus facilitating “learning by doing” **(Kamarainen et al., 2013, Wang et al., 2014)**.

Zarraonandia A. et al. (2013) defined advantages; they stated that AR increases communication and interactions among teacher-students. AR technology was said to be useful for visually supporting students in physics education, and for enabling their visualization of intangible concepts. It is also easy for students to use **(Zarraonandia et al., 2013)**. For example, **(Apittha et al. 2019)** studied some data with learners participated in an unstructured physics activity with and without AR. The results were that participants they interacted with an augmented sound producing speaker. and they learned more about visual concepts (ex: magnetic field structure and stopped exploring the system faster than non-AR participants, also they used less aids in exploration and teaching and spent less time in teaching their collaborators **(Apittha, 2019)**. Interactivity can activate knowledge stored in long-term memory and cause the brain to integrate it with incoming information. Students who interact with the content can remember more than students who receive information only passively and better transfer what they have learned to new problems **(Abu-Dalbouh et al., 2020)**.

4.2. The effectiveness of AR apps in teaching students the physics experiments.

Experimental teaching is an essential link in physics teaching and learning activities, holding an important position in the modern education. Learning with hands-on experiments can be supported by providing essential information virtually during lab work. There are a number of possible learning goals for Experimental teaching courses such as reinforcing physics concepts, developing laboratory skills **(Zaghloul, A. R. M. (2001)**. Although there are several challenges inherent insufficient laboratory equipment, equipment error, difficulty in simulating certain experimental conditions, Augmented reality (AR) appears especially suitable for presenting information during experimentation, as it can be used to integrate both physical and virtual lab work. Virtual information can be displayed in close spatial proximity to the correspondent components in the experimentation environment, thereby ensuring a basic design principle for multimedia instruction: the spatial contiguity principle **(Strzys et al., 2018)**.

Many previous studies applied augmented reality to the teaching of physical experiments, and there have been positive results that show us the effectiveness of applying augmented reality in supporting real laboratories such as increases the creative thinking skills and problem-solving skills in students **(Duban, 2019)**. The use of AR media in the form of video in experiment activities in the laboratory can improve the development of student laboratory skills. Besides, the researchers also can help student complete laboratory activities in a shorter time so that they have more time to discuss the results of the experiment, it could make time-efficient **(Akçayır and Pektas, 2016, Nadelson, 2014)**.

Experiment learning in the laboratory also required teaching materials in the form of student worksheet that can direct students to work. The AR videos are incorporated with student worksheets to help students in practicing until they find physics concepts. Discovery learning is a learning model that can help students to increase their active role so that they can construct their understanding and knowledge **(Bower et al., 2014, Bakri et al., 2019, Martaida et al., 2017)**.

The success of physics lab courses is often discussed with respect to three potential learning goals: reinforcing physics concepts, developing lab skills, and fostering expert like beliefs about the nature and importance of experimental physics. In this review we reviewed some studies and summarize their results in table 1, which show that AR-based physics laboratories can be opportunities for future research .

Table 1. The studies on the use of AR technology in physics subjects and its learner's outcomes.

Study	**Experiment subject**	**Experimental application method**	**Educated class**	**Learner outcomes**
Ibanez et al. (2014) (Ibanez et al. 2014).	Electromagnetic field	AR-based, web-based	Secondary school	Motivation, learning outcomes, Concentration, sense of control, clearer direct feedback, and autotelic experience, A deeper analysis
Wang et al. (2014) (Wang et al., 2014).	Elastic collision	Augmented reality (AR) simulation system	University	Learning outcomes. The system supported students' collaborative, students showed high frequencies on higher-level inquiry behaviors.
Enyedy et al. (2012) (Enyedy et al., 2012).	Newtonian force and motion	The Learning Physics through Play Project (LPP)	Primary school	Learning outcomes; students were able to develop a conceptual understanding of force, net force, friction and two-dimensional motion.
Fauzi Bakri, Shabrina Pratiwi, and Dewi Muliyati, (2019) (Bakri et al., 2019).	The heat	The Dick and Carey model worksheets	school students	Improve student learning, developed a student's critical thinking skills
Harun, Neha Tuli, and Archana Mantri, (2019)	Fleming's rule in Electromagnetism	AR technique and the visualization.	high school students	Enhancing students' knowledge learning achievement, increase students' educational

(Harun et al., 2020).				achievement in the learning procedure
Yevgeniya Daineko et al., (2020) (Daineko et al., 2020).	Several experiments	Using the desktop-based VR, VR with the Leap Motion controller	Secondary educational institutions	Useful for studying physics, usability.
Yau C. D. et al., (2020) (Yau et al., 2020),	Direct current glow discharge experimentation	Direct AR application lab.	High school students	Advantage of allowing students to conduct experimentation without removing any of the real-life. AR is easy for students to use, helps students to understand. Enhancing satisfaction.
Aoki Y. et al., (2020) (Aoki et al., 2020).	Systems displaying three-dimensional dynamic motion in real time	a three-dimensional motion tracking system	Schools	Intuitively understand dynamics in the study of physics. Enables visualization of invisible concept, events, and abstract concepts
Luisa Lauer et al., (2020) (Lauer, 2020).	Real-time visualization of electrical circuit schematics	AR system using either smartglasses or tablet computers	Students in introductory physics education	AR-experiment allows for encountering learning difficulties concerning simple electrical circuits in introductory physics courses. conceptual knowledge acquisition.
Strzys, M. P et al., 2017 (Strzys et al., 2017).	The thermal flux(Heat conduction) experiment	The MR setting with AR	University	Extend human perception to new regimes, e.g., temperature and heat, thereby strengthening the connection between theory and experiment. spatial and time contiguity which is supposed to support the learning process of the students.

				the just-in-time evaluation of the data. and immediately compare the outcome to theoretical predictions. deepen student's physical understanding.
Strzys M. P. et al., (2018) (Strzys et al., 2018)	Using Smartglasses for Augmented Reality labwork to foster the concepts of heat conduction	HoloLens	University	increase students' conceptual understanding.
Wang T. et al., (2018) (Wang et al., 2018).	Double-Slit Experiment	DSIAR (an AR-based interactive application on mobile devices). simulation application.	University	Attracting students' attention and stimulating their interest. Increase students' educational achievement in the learning procedure. Increases the interaction between students and material.
Bakri F., Sumardani D. and Muliyati D., (2019) (Bakri et al., 2019).	Lorentz Force	simulation by utilizing augmented reality technology, by pedagogical content knowledge (PCK).	University	Better understanding. enhance learning, skills, and outcomes, especially for practical skills.
Nareg Minaskan et al., (2019) (Minaskan et al., 2019).	Object motion and collisions on a nearly frictionless surface.	Two versions of such an AR system, using an HMD and a projector respectively.	University and technology museum	understanding of the laws of classical mechanics related to velocity, energy and momentum during collisions.
Knierim P, Kiss F., and Schmidt A., (2018)	Thermal Flux	AR view of real-time data	High school	hands-free interaction and supports multiple users to enable students to collaborate, providing,

(Knierim et al., 2018).				students get real-time feedback and enhanced data visualization, foster a deeper understanding of the learning material. acquired knowledge in thermodynamics.
Thees M. et al., (2020) (Thees et al., 2020).	Heat conduction Examining	AR view of real-time data	University	Integrate presentational format of live data visualizations.
Su Cai, Feng-Kuang Chiang, and Xu Wang, (2013) (Cai et al., 2013).	The convex lens image-forming experiment	3D AR learning environment (vivid real-time demos)	School's students	The mean scores of the experimental group increased, increase attention and increase learning motivation in physics courses, promote student's level of activity.
Daineko et al. (2018) (Daineko et al. 2018)	Mechanics	Computer graphics, AR application.	Secondary school	Practical tasks
Altmeyer, K. et al., (2020) (Altmeyer et al., 2020)	Electric circuits	A tablet-based AR application	University, School	Higher conceptual knowledge gains. Provide additional virtual information to learners, affordable alternative.

Interpretation of table-1.

It is inferred from the above table that there are many advantages to using augmented reality in teaching physics experiments, through which reinforcing physics concepts, developing lab skills, and fostering expert like beliefs about the nature and importance of experimental physics for students, which show that AR-based physics laboratories can be opportunities for future research in physics education.

4.3. Challenges of using augmented reality in physics education.

Though AR provides many advantages in physics educational settings, researchers have reported some challenges imposed by AR technology. Maybe in future studies the researchers will find solutions for these challenges.

The most reported challenge is Developing AR applications is a costly requiring the creation of interactive 3D experiences through use of specialized engineering skills and expensive technologies **(Iulian and Bertrand, 2019)**.

One of the challenges is that because of the novelty of the AR technology, the students may experience difficulties when using this technology which affects educational effectiveness, and that may cause time loss for students and may require excessive additional lecture time **(Gavish et al., 2015)**. Another studies indicated that usability issues must be addressed because AR technology involves extensive user interaction. For example, without well-designed interfaces, students may experience difficulties when using this technology **(Chiang et al., 2014, Chen and Tsai, 2012)**. According to **(Claudia et al., 2019)** , instant hints or learning guidance could be provided to students to prevent AR usability issues **(Claudia et al., 2019)**. Another challenge is that Understanding the AR representations need that students have basic background knowledge of the concepts taught, and In a classroom setting, teachers should make sure that more explanations are provided about interpreting the AR visualizations so that students do not develop misconceptions.

Somestudies focused on some drawbacks such as prevent learners from focusing on more kinesthetic information, that due to highly stimulating AR visualizations. For example, Iulian & Bertrand, (2019**)** one issue they observed was that the students that had AR educational content did not know how to make sense of the magnetic field since they had no prior exposure to this this type of representation. This led to problems such as interpreting field strength based on the size of the magnetic field lines rather their density. This was likely caused by highly stimulating AR visualizations, which may have prevented learners from focusing on more kinesthetic information. Other observation was that participants seemed to be overwhelmed by the amount of information and had difficulty noticing important events in the system (e.g., changes in the magnetic field) **(Iulian and Bertrand, 2019)**.

According to the results in our review, there are other challenges for using AR technology in physics education, such as the technological tools used in this technology, the recent studies showed that The efficiency of augmented reality varies according to the tools associated it.

Thees et al., (2020) applied AR applications to a physics laboratory experiment examining heat conduction where students measure the temperature along heated metal rods via a thermal imaging camera. However, the traditional setup leads to a time delay between measuring and receiving data, and spatially separates relevant visualizations causing resource-consuming search processes. Using see-through smartglasses, traditional displays were transformed into virtual representations which were anchored to corresponding objects of the experimental setup, resulting in an integrated AR view of real-time data **(Thees et al., 2020)**. Although **(Kapp et al., 2020)** indicated that the limitations of AR in educational settings, where is the results showed that limited field of view of the smartglasses, that due to unable to register all visualized measurement values at once. but the use of tablet-based AR was able to register them simultaneously due to the presentation on a tablet screen. The researchers also indicated that effective AR-supported learning smartphones can be used too, and the same effect might be reached using a future generation of smartglasses with an extended field of view, potentially leading to more pronounced effects compared to tablet based AR and reduce interruptions, so Further studies should evaluate the effects associated with the technological tools which used in this technology **(Altmeyer et al., 2020, Kapp et al., 2020)**.

The most important challenges identified by reviewing previous studies for using AR technology in physics education is that need to expand research about using AR technology in educational fields and developing methodologies that use AR to favor physics subjects that contain complex concepts and require advanced technological laboratories. Also, the need to create and put into operation platforms or authoring tools that make use of AR and that are directly oriented to the attention of the diverse educational needs of students at different educational levels, with considering the diverse needs such as educational needs of students who are deaf, blind, with impairment and autism, dyslexia, Down syndrome, attention deficit, hyperactivity (**Nor et al., 2015)**.

Physics education applications using augmented reality technology, which has been developed extensively in recent years, have a lot of restrictions in terms of performance and accuracy. so some recent studies research to develop a real-time simulation system for physics education that is based on parallel processing. Such as Nak-Jun Sung et al., (2019) study presented a video see-through AR system that includes an environment recognizer using a depth image of Microsoft's Kinect V2 and a real-time soft body simulator based on parallel processing using GPU (Graphic Processing Unit). Soft body simulation can provide more realistic simulation results than rigid body simulation, so it can be more effective in systems for physics education. so they designed and implemented a system that provides the physical deformation and movement of 3D volumetric objects, and uses them in education. they verified the usefulness of the proposed system by conducted a questionnaire survey of students majoring in physics education. As a result of the questionnaire survey that they would like to use it for education **(Nak-Jun et al. 2019)**.

Some advantages and challenges results apparently conflict with each other in the literature. For example, some studies reported that AR is difficult to use in complex physics concepts learning such as electromagnetism, while others stated that ease of use is an advantage. Similarly, it is not clear whether AR applications might cause cognitive overload. So it need more future studies.

5. Recommendations

The following existing gaps and needs in AR research were derived from the findings of this review. These points are presented to guide future research are provided below:

- The results suggest that AR should not be considered as an independent learning environment for the teaching of physics, but would be more effective as supplementary to laboratory activities rather than replace traditional curriculum material.
- more studies about the advantage and benefit of augmented reality for the subjects that are understood hardly, like magnetism can be understood more easily and efficiently by the students.
- Future studies about teachers' education about augmented reality with seminars to use it in their lessons efficiently. encourage them to practice AR in the classroom since they will discover the educational potential of AR.
- The conditions relating to the problem of cognitive overload in AR technology applications should be researched (topic, age group, interface characteristics, etc.).
- Future research may investigate the use of AR applications to support ubiquitous physics learning and informal learning, how they should be used, and the potential of AR could be further expanded by designing it for implementation with diverse populations, such as students with special needs, and preschool students, parents and graduate students.

- Future research can determine the best tools-based AR application (tablet-based AR, smartglasses, smartphones, etc.), and reveal whether the success of the applied AR-supported learning environment is influenced by the individual differences of the learners, such as their cognitive abilities, as well as their emotions. Since AR-supported lab work integrates both, future studies should consider process-based measures, such as eye tracking to investigate, how AR affects attentional l processes during learning. The newly established AR-based representation of measurement data during lab work has been shown to be appropriate as a tool to support physical experimentation.
- More studies related to the development and usability of AR applications are needed. learners' opinions about usability and preferences must be examined in AR based learning environments. their suggested solutions to problems which they encountered should be more deeply explored. Additional research could be directed toward student satisfaction, motivation, interactions, and student engagement to better understand the advantages of AR in educational settings.
- Future studies on integrating augmented reality technology into smartphones applications and electronic gaming market to simulate physical concepts and experiments.
- In the future, physics book development based on augmented reality technology should develop for other subjects. It is necessary to hold the experimental research for the effectiveness of this augmented reality physics book using in learning.
- Future studies about teaching complex physics topics for young children such as (force, friction and two-dimensional motion ... etc.) by usable and interesting ways using AR technology to develop a conceptual understanding for them .

6. Conclusion

This study examined 102 educational AR articles indexed in Google Scholar, ScienceDirect and open access journals are referred as primary databases to search the literature with content analysis method. we focused on Data analyses set out to establish trends in physics education AR studies. Content analysis of articles reveals that 3D models are popularly used in augmented reality for physics education.

The number of physics education AR studies has increased over the years. It is foreseen that physics education AR will be more widespread in the future along with recent advances in tools technologies. The significance of AR use for physics educational purposes and the increase in the number of studies will continue in the upcoming years. It can be argued that the results of this review are significant to guide future studies.

Research results present that AR is a technology used in physics education and include physics challenging concepts and experiments, that due to a unique characteristic of AR: combining real and virtual. With this characteristic, AR stands out as an effective educational tool that can be used for physics education. Previous studies have shown that AR has many advantages in physics education, such as interesting and enjoyment in science learning, stimulating and motivating students towards gaining scientific knowledge in physics' materials and concepts. Teaching materials can support student learning and increase student success. Emerging technologies such as Augmented Reality (AR), have the potential to radically transform education by making challenging concepts visible and accessible to novices. We believe augmented reality has the potential to radically transform formal and informal education by making challenging concepts visible to novices. From this review, it is found that rather than just using text and images, the assistance of audio or three-dimensional models with animation as well as the two-dimensional or three dimensional video would provide a deeper understanding and cultivate interest.. However, But, as with all technologies, there are some challenges to be considered when using AR. will likely be resolved by new developments in the future. It should also be noted that there are some prerequisites for the use of this technology, such as hardware (mobile devices, tablets, etc.) and an Internet connection. When these requirements to use AR applications are met and the challenges are considered, AR applications should be even more useful in education.

Future work may focus on augmented reality-based physics laboratory experiments notably for Physics learning. It is quite well known that Physics comprised of plenty of complex procedures and abstract processes to follow. It does also require a good visualization ability to visualize the complex concepts.

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