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LITERATURE REVIEW

Augmented Reality-based Physics Learning Media To Improve Students' Motivation And Learning Outcomes: A Systematic Literature Review

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Abstract

Physics is widely regarded as one of the most challenging subjects for students due to its abstract concepts and unengaging teaching methods, often resulting in low motivation and poor achievement. To address these challenges, this study systematically examines the impact of Augmented Reality (AR) on enhancing student motivation and learning outcomes in physics education, analyzing 20 articles published between 2019 and 2024 through the Systematic Literature Review (SLR) method, guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol. The findings reveal AR's significant potential to transform physics education by visualizing abstract concepts and creating interactive, engaging learning experiences, addressing limitations in traditional methods. However, barriers such as high device costs, limited infrastructure in underdeveloped areas, inadequate teacher expertise, and a lack of diverse AR content hinder its widespread adoption. Long-term research is recommended to evaluate the sustained impact of AR on learning outcomes and motivation across different educational levels and contexts. By addressing these challenges, AR has the potential to become a transformative tool, making physics education more inclusive, engaging, and impactful while fostering a deeper understanding of complex concepts and improving student motivation and achievement.

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INTRODUCTION

In the 21st century, science and technology are important factors in education (McFarlane, 2013). Physics is one of the most challenging and less interesting subjects for students (Ibrahim et al., 2024). As a result, physics is one of the subjects that students have little interest in (Socrates & Mufit, 2022; Siahaan et al., 2019) . During physics learning, irrelevant methods, monotonous learning, and lack of innovation cause low student achievement (Rozi et al., 2024; Ramadhan et al., 2023). Therefore, teachers must create teaching and learning activities that attract students' interest by using more inventive physics learning media (Hartono, 2022; Novita, 2023; Ramadhan et al., 2023).

Learning media helps the teacher summarize the lesson and serves as an intermediary (Lai & Cheong, 2022), helps students to learn effectively, and encourages creativity (Socrates & Mufit, 2022). They also help teachers increase student motivation during learning activities (Hizbi & Syahidi, 2020). Learning media can provide learners with the opportunity to follow learning activities independently and efficiently (Ibrahim et al., 2024; Önal & Önal (2021); Ferdiman et al, 2023). This allows learners to understand what they are learning. Teachers should choose the type of learning media based on student preferences, technology, and ease of access (Rohmaniyah et al., 2017). If the selection of media is not based on students' ability to use it, learning activities will run less effectively and learning objectives will be difficult to achieve. In other words, learning media is essential for enhancing the educational process, making the learning experience more effective (Holly et al., 2023).

Technology that can be used in education develops along with the times (Lai & Cheong, 2022; Fidan & Tuncel, 2019). Technology in the classroom can increase student interest, motivation, and engagement (Hartono, 2022; Hermawan & Hadi, 2024). It can also help students learn physics in a more active, exploratory, and critical way (Gregorcic & Haglund, 2021; Lai & Cheong, 2022; Ferdiman et al., 2023). Students will be more interested in learning in class if the media used by the teacher to deliver the lesson is interesting and supported by a communicative and active teacher (Ibrahim et al., 2024). Therefore, the use of interesting and unique learning media in addition to being used on Android will make students more interested in learning (Hermawan & Hadi, 2024). However, strong motivation can improve learning achievement by encouraging better thinking, concentration, and learning (Arymbekov et al., 2024; Khalilullah et al., 2023). Motivation encourages students to try harder to complete their tasks (Filgona et al., 2020). To get motivation to learn from teachers and students themselves, internal motivation comes from students (Ryan & Deci, 2020), and external motivation comes from teachers and the learning environment, including learning media (Safaruddin et al., 2020; Ramadhan et al., 2023).

Augmented reality (AR) is one of the most potential technologies to be used in physics learning (Ferdiman et al., 2023; Fidan & Tuncel, 2019; Lampropoulos et al., 2022; Wulandari et al., 2022). AR, especially as learning media, has been used significantly in many fields, including physics education (Afifah et al., 2020; Rohmaniyah et al., 2017;

Rozi et al., 2024; Timur, 2022). Using Augmented reality (AR) in learning can create an interactive, interesting, and immersive learning environment (Lytvynova & Soroko, 2023; Kiryakova, 2020). This allows learning to be more flexible and in line with the real world (Thees et al., 2020). AR applications benefit learning achievement, attitude, motivation, and cognitive stress.

Technology should be used to make learning more varied again Loderee et al., 2020). One example is the use of Augmented Reality (AR) in the learning environment (Vidak et al., 2024). By using AR, students' learning achievement can improve compared to traditional learning methods at all levels (Anggrawan & Satria, 2023; Thees et al., 2020) . This is because viewing electronic devices can help students understand the limitations of conventional learning (Dewi et al., 2022; Hartono, 2022).

Studies on the use of Augmented Reality (AR) in physics education have shown that this technology can improve students' understanding of ideas and desire to learn Cai et al., 2021). However, most existing research focuses on the short-term impact of AR, with little research studying the long-term impact of AR on student learning outcomes. Due to these limitations, there is not enough literature on how AR can affect better understanding of physics or retention of physics concepts consistently. In addition, since these studies were mostly conducted in places with adequate technological infrastructure, the results may not be relevant in places with limited devices or technological access. This makes it important to understand how AR can be applied to various educational situations, especially in resource-constrained environments.

The purpose of this literature review is to support educators in implementing AR in physics classes in an effective way (Post et al., 2020; Tsiotsou et al., 2022). This review not only demonstrates that AR is effective, but also provides new understanding of how this technology can be applied in situations with limited infrastructure. It is hoped that this guide will enrich the literature and provide added value to educators and researchers interested in creating more interactive and meaningful physics learning experiences for their students.

Therefore, researchers studied and analyzed further articles written by other researchers about the application of augmented reality as a physics learning media. The goal is to identify and find out how the effectiveness of Augmented Reality in increasing student interest in physics subjects, challenges in the implementation of Augmented Reality and find out whether the use of augmented reality in physics learning has a long-term impact on student motivation and learning outcomes.

METHOD

To investigate the impact of using *Augmented Reality* (AR) in physics learning, we used a *systematic literature review* (SLR) approach. This is due to the fact that this learning method is best suited for finding and analyzing research results through a systematic approach, through rigorous selection (Mun et al., 2018). Systematic review guidelines are built under the *Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA)

(Page et al., 2021). This approach was chosen because it provides a structured framework in identifying, screening, and analyzing articles related to the use of AR learning media in physics learning.

Data Source

Two major databases, Publish or Perish and Scopus, were used to obtain the articles analyzed. These databases were chosen because they provide access to high-quality articles relevant to the research topic. Using keywords such as “augmented reality,” “physics learning media,” and “education,” the search focused on articles published from 2019-2024 to ensure that the data analyzed reflected the latest trends and information on the use of Augmented Reality (AR) in physics learning.

Selection Criteria

In this research stage, the article selection process was carried out using the following inclusion and exclusion criteria:

Inclusion Criteria.

To be included in the research analysis, researchers ensured that the articles used were highly relevant to the research objectives and supported data quality. The categorization process of the inclusion criteria is shown in Figure 1. "Published articles (2019-2024)" refers to scholarly articles published between 2019 and 2024, covering various topics, methodologies, and findings, and typically accessible through academic journals, databases, or sources like Publish or Perish and Scopus. An article on AR in physics learning explores how AR technology enhances student engagement and understanding by visualizing complex physical concepts and experiments, providing interactive, immersive experiences in the classroom. The last step is selecting articles that involve junior high school, senior high school, or college students as research subjects

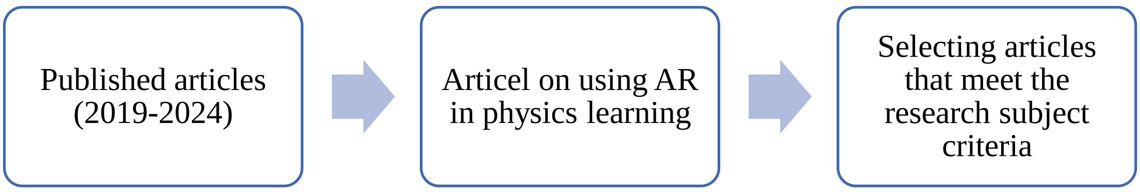

Figure 1. Process for inclusion criteria in research analysis

Exclusion Article Criteria

Exclusion criteria help filter out irrelevant or invalid articles. These criteria define articles that are not suitable for inclusion in the analysis. Several criteria for article exclusion are irrelevant topic (content that does not directly relate to the AR and research subject area), does not meet methodological standards, year of publication out of range, inappropriate research subjects, and duplication.

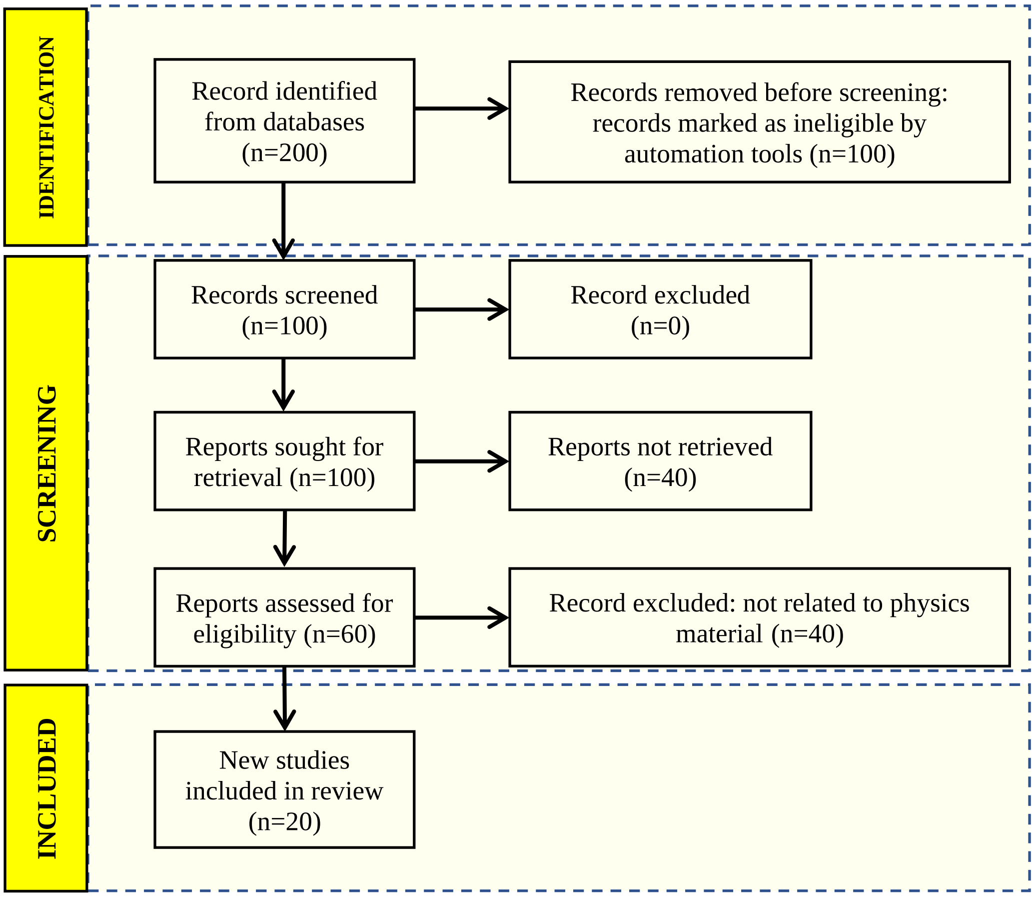

Figure 2. Flowchart of preferred reporting items for systematic reviews and metaanalysis (PRISMA)

Research Design and Procedures

To start the investigation, 200 articles were retrieved from Publish or Perish and Scopus. Using Excel, the collected articles were screened starting from their titles and abstracts. After that, we found that 100 articles were not used (articles did not meet the requirements, such as year of publication, same article, and suitability to the journal to be analyzed). Next, no articles were excluded and 40 articles were excluded because they did not focus on students (Junior high school, senior high school, or college student), resulting in 60 complete articles. In the last stage, 60 articles were identified, and 40 articles were excluded because they did not relate to physics material. As a result, the last 20 articles will be analyzed. A graphical representation of the citation flow reviewed during the systematic review process is encapsulated in Figure 2.

RESULT AND DISCUSSION

The 20 selected articles were then studied thoroughly to answer the research questions. The results of the analysis of the 20 articles can be observed in Table 1.

Table 1. Results of articles' analysis

No.	Author Name	Methods	Material	Aspects measured	Assessment Results
1	Hermawan, A., et al. (2024)	Experi-ment	AR in Conceptual Understand-ing	Concept Mastery	AR-based media showed significant improvement in students' concept understanding.
2	Ibrahim, M. A., et al. (2024)	Experim ent	AR for Motion and Force in Physics	Conceptual Understandi ng, Engagement	AR-based media increases interest and understanding of concepts in mechanics.
3	Rahma et al. (2024)	Litera-ture Review	AR-based LKPD in Science Education	Effectivenes s on junior high school students and learning outcomes	AR-based LKPDs improve student engagement and learning outcomes.
4	Vidak, A., et al. (2024)	Systema tic Review	AR in Physics Education	Opportuni-ties Challenges	A comprehensive review demonstrates the role of AR in improving engagement and learning, despite technical limitations.
5	Arzak & Prahani. (2023)	Literatu-re Review	Interactive Media	Learning Outcomes	AR as an interactive media to improve student learning outcomes.
6	Ferdiman et al. (2023)	ADDIE Model	Newton's Law	Concept Understandi ng, Learning Interest	AR application can improve students' understanding of Newton's Law concept and learning interest.

7	Khalilullah, M., et al. (2023)	Instru-ment Develop ment	Science Literacy with AR	Science Literacy	AR-based media improves science literacy through interactive content.
8	Ramadhan, I. R., et al. (2023)	Experim ent	AR in Straight Motion	Concept Mastery	AR helps master the concept of straight motion in physics education.
9	Dewi et al. (2022)	R&D (4D Model)	General Physics	Motivation, Learning Outcomes	AR media significantly improves motivation and learning outcomes.
10	Hartono, H. (2022)	Quasi-Experim ental	AR in Physics Learning	Learning outcomes	The positive impact of AR in physics education on student learning outcome
11	Lai, J. W., et al. (2022)	Systema tic Literatu-re Review	AR in Physics Education	Opportuniti-es, Challenges	AR presents immersive learning opportunities, but also technical challenges.
12	Lampropou los, G., et al. (2022)	Systema tic Literatu-re Review	AR and Gamification in Education	Application, Effective-ness	AR increases engagement through gamification, but it needs careful design to impact learning.
13	Socrates & Mufit (2022)	Literatu-re Review	Physics	Effective-ness, Learning Outcomes	Comprehensive literature suggests the effectiveness of AR in improving learning in physics education.
14	Wulandari, N., et al. (2022)	Develop ment & Experim entation	AR in Geometric Optics	Concept Mastery	Significant positive impact on students' understanding of optical geometry using AR
15	Afifah, et al. (2020)	Develop ment & Feasibili ty Study	Kinetic Theory of Gases	Content & Display Feasibility	AR-based media is suitable for kinetic theory education.

16	Thees, M., et al. (2020)	Experim ent	AR in University Physics Laboratory	Cognitive Load, Learning Outcomes	AR reduces cognitive load while enhancing learning in the lab.
17	Timur, K. J. (2022)	Develop ment	AR Glossary for Modern Physics	Concept Mastery, Understandi ng	The AR-based glossary supports a deeper understanding of modern physics.
18	Fidan & Tuncel (2019)	Problem -Based Learnin g (PBL) with AR	Force and Energy	Learning Achievement , Attitude	PBL assisted with AR improves students' learning achievement and positive attitude towards physics.
19	Rohmaniya h, I. A., et al. (2019)	R&D (4D Model)	Global Warming with AR in Physics	Cognitive Learning Outcomes	AR media showed high effectiveness in improving students' cognitive performance.
20	Siahaan, A. D., et al. (2019)	Literatur e Review	AR in Physics Education (General)	Concept Mastery Engagement	AR significantly improves engagement and mastery of complex physics concepts.

The articles presented in Table 1 were thoroughly analyzed from abstract to conclusion, and several key findings were identified. First, based on research methods, the studies utilized three primary approaches. The experimental method was employed in studies by Hartono (2022), Hermawan & Hadi (2024), Thees et al. (2020), Ibrahim et al. (2024), Ramadhan et al. (2023), and Fidan & Tuncel (2019). The media development method, including research and development approaches, was adopted in studies by Dewi et al. (2022), Rohmaniyah et al. (2017), Afifah et al. (2020), Wulandari et al. (2022), Timur (2022), Khalilullah et al. (2023), and Ferdiman et al. (2023). Lastly, the literature review method was evident in works by Aulia Rahma et al. (2024), Lai & Cheong (2022), Lampropoulos et al. (2022), Siahaan et al. (2019), Socrates & Mufit (2022), Vidak et al. (2024), and Arzak & Prahani (2023).

Second, by education level, the studies focused on junior high school, senior high school, and university contexts. For junior high school, studies included those by Aulia Rahma et al. (2024), Ramadhan et al. (2023), Arzak & Prahani (2023), Lai & Cheong (2022), Lampropoulos et al. (2022), Hermawan & Hadi (2024), Khalilullah et al. (2023), and Fidan & Tuncel (2019). The senior high school category was represented by works such as Afifah et al. (2020), Hartono (2022), Ibrahim et al. (2024), Wulandari et al. (2022), Rohmaniyah et al. (2017), Socrates & Mufit (2022), Siahaan et al. (2019), Vidak et al. (2024), Dewi et al. (2022), and Ferdiman et al. (2023). At the university level, studies were conducted by Timur (2022) and Thees et al. (2020). This diverse distribution highlights the application of AR technology across various educational stages, offering insights into its benefits and challenges in distinct academic settings.

Problem Encountered in the Current Learning Process

The problem that occurs in the current learning process is the lack of interest and learning outcomes in students based on the analysis of articles in Table 1, among others:

Lack of Student Motivation and Interest in Learning Physics

Some journals, such as those written by Lai & Cheong (2022), and Vidak et al., (2024) emphasize that one of the main obstacles in using AR in schools is technical constraints related to hardware and software. Many schools, especially in less developed areas, do not yet have adequate infrastructure to support the use of AR. Infrastructure such as smartphones or tablets compatible with AR applications may not exist. In the absence of interactive media that supports learning, it is possible that students lack interest in learning and learning outcomes. Students' focus on learning will decrease which causes their educational achievements to decrease

Lack of Knowledge and Skills of Teachers in Using AR

Most of the literature, such as Dewi et al. (2022) shows that teachers lack the ability to effectively utilize AR technology in the learning process. As technology develops faster than the training provided to teaching staff, many physics teachers are not familiar with the use of AR, so they have difficulty integrating it into their subject matter. This problem becomes more complex as the technology advances. As a result, AR cannot be maximized in improving learning outcomes.

Limited AR Content Specific to Physics

Journals on media development, such as Wulandari et al., (2022) and Afifah et al., (2020) emphasize that physics-specific AR content is still limited, especially in junior and senior high schools. Many AR applications are made to support physics learning or only cover some curriculum. For example, only some basic concepts such as momentum or optics are used in augmented reality (AR) content. In contrast, more complex concepts such as electromagnetic fields or quantum mechanics are still rarely used in AR content.

Potentially Increased Student Cognitive Load

It is often said that AR can decrease students' cognitive tasks, but studies like Thees et al. (2020) found that this technology can actually increase cognitive tasks. This happens when the use of AR is not combined with the right learning design. For example, when too many visual elements or information are presented through AR, students can have difficulty processing the information. This is especially true for students who are new to AR technology or have not mastered the basic concepts required before using AR media.

Limited Research on the Long-term Effectiveness of AR

Some of the journals analyzed, such as Arzak & Prahani (2023), Ferdiman et al., (2023), Socrates & Mufit (2022), and Lampropoulos et al., (2022) show that AR is effective in improving student learning outcomes and motivation. However, these studies mostly focus on short-term measurements. How the use of AR impacts student learning outcomes in the long term is still the subject of little research. Do students stay motivated and understand more after several months or years of AR use? To date, this question is still an issue that has not been widely addressed in the literature.

Challenges in Design and Development of Interactive and Relevant AR Content

Journals such as those written by Khalilullah et al. (2023) and Masrifah et al. (2021) emphasize that although Augmented Reality can improve science literacy and science process ability, the development of interactive and relevant AR content is still a challenge. Many current AR applications do not provide enough interactivity to encourage students' deep engagement with the material. In fact, AR should be designed so that students can actively participate and work together in solving physics problems. Additionally, the AR application used in the research by Fidan and Tuncel (2019) was designed as marker-based, which is prone to technical issues such as difficulty in recognizing markers under poor lighting conditions. This presents a challenge for the implementation of AR in diverse learning environments.

Solution to the Problem

Improved Technology Infrastructure in Schools

There needs to be greater investment in school technology infrastructure, especially in less developed areas, to overcome the technical challenges of implementing AR. The private sector and government can work together to provide adequate hardware, such as smartphones or tablets, that students can use during learning. In addition, the development of AR applications that can be used on devices with low specifications is also an important way to increase the accessibility of this technology among different students.

Teacher Training and Skill Development

Continuous training should be provided to physics teachers to address teachers' limited knowledge on the use of AR. This training should address not only how to use AR technology, but also how to combine it with effective learning approaches. To ensure that AR can be used as an optimal tool in physics learning, teachers should be equipped with pedagogical and technical knowledge. Discussion forums between teachers can also be used to share experiences and best practices of using AR.

Broader and Deeper AR Content Development

Not only should AR content be limited to basic physics concepts, but also more advanced disciplines such as electromagnetics, quantum mechanics, or particle physics. Involving more academics and educational media developers will help solve the problem of AR content limitations. In addition, collaboration between educators, students, and content developers can help ensure that the content created meets academic standards.

Appropriate Learning Design to Reduce Cognitive Load

To avoid cognitive overload, augmented reality (AR) content should be designed with students' cognitive abilities in mind. Learning design using AR should also ensure that information is presented gradually and not too overwhelmingly. In addition, AR should be used as a tool that complements traditional learning rather than replacing it completely. In addition, the use of scaffolding, or gradual assistance, can help better understand the material without becoming overwhelmed.

Further Research on the Long-term Impact of AR

Further research is needed to answer questions about the effectiveness of Augmented Reality in the long term. This research should track student learning outcomes and motivation in both the long and short term. Long-term research that tracks student progress after several years of using Augmented Reality in physics learning can provide deeper insights into how AR affects student motivation, understanding, outcomes and achievement consistently.

The usefulness of AR in Physics Learning:

In the world of education Augmented Reality (AR) has enormous potential, especially in physics learning, with some of the main benefits as follows:

Improving Visualization of Abstract Concepts

AR is easy to understand and makes learning more real because it helps students see abstract physics concepts such as electromagnetic waves, electric fields, and particle dynamics.

Increasing Student Engagement

Through augmented reality (AR) applications, students can directly interact with physics objects, making learning interactive and more interesting.

Improving Understanding and Learning Outcomes

Studies show that AR can assist students in understanding physics concepts that are difficult to grasp with just text or static images.

Supports Independent Learning

a) Students have the ability to independently explore physical objects outside the classroom with AR. This supports exploratory learning and reinforces classroom learning outcomes.
b) Studies conducted by (Ibrahim et al., 2024) found that learning physics using AR can improve student learning outcomes by up to thirty percent compared to conventional methods. This finding is in line with previous research that says AR not only helps students understand abstract concepts such as electromagnetic waves, but also increases their overall engagement.

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Physics Topic

The physics topics used in the development of augmented reality in 20 articles are presented in the Table 2.

Table 2. Materials used

No.	Material	Level	Total
1	Kinetic Theory of Gases	Senior high school	1
2	Science	Junior high school	8
3	General Physics	Senior high school	5
3	Geometric Optics	Senior high school	1
5	Modern Physics	Senior high school	1
6	Straight Motion	Senior high school	1
7	Motion and Force	Senior high school	1
8	Physics	College student	2

The results of the analysis in the table above obtained material used in learning and Augmented Reality and 20 articles. According to the results of the analysis carried out in the table that has been presented, the material used in Augmented Reality (AR) learning in the 20 articles analyzed covers a variety of physics topics that are relevant for junior high school, high school and college students. Widely used materials, such as general physics, physics and ipa show that students really need to understand the basic concepts of physics, which are often considered difficult to learn. This shows that Augmented Reality not only offers new learning options, but also answers physics problems in an interesting and more interactive way.

So the conclusion of the grouping of 20 journal articles is as follows:

Use of AR in Physics Learning in General

A cluster of 20 journals that have been analyzed show that Augmented Reality (AR) is very helpful in improving students' interest and learning outcomes in physics learning, especially in junior and senior high school. Most studies show that AR not only makes abstract and complex concepts easier to see, but also makes the learning atmosphere effective and more interactive, making students more engaged while learning.

Journals such as Afifah et al. (2020) and Wulandari et al. (2022) found that augmented reality helps students see difficult physics concepts, such as kinetic theory of gases and geometric optics. AR allows students to see simulations of physics concepts that were previously difficult to imagine through conventional learning methods.

In their research on the application of augmented reality (AR) in university physics laboratories, Thees et al. (2020) emphasized that AR reduces students' cognitive load, which means students can focus more on understanding concepts without experiencing excessive confusion in understanding abstract theories. This result was followed by a significant improvement in learning outcomes.

AR Increases Student Learning Interest

One of the main problems in learning physics is the desire to learn, which is often considered difficult and uninteresting for students. However, AR offers a solution by making learning more fun and engaging, especially thanks to the use of interactive elements and 3D visualization.

Arymbekov et al. (2024) found that interactive 3D AR successfully increased students' motivation and engagement in learning physics, especially for the digital generation who prefer inventive technology-based learning approaches.

Önal & Önal (2021) found that in the discovery learning model, AR can significantly increase students' interest in learning. This is due to the fact that interactive visualization increases students' interest in the material presented. This interest reduces boredom in physics learning because it makes the learning experience more active and participatory.

AR Improves Student Learning Outcomes

The experimental method is widely used by researchers at various levels of education which shows that, in addition to increasing interest, student learning outcomes also increase with AR learning media.

In his research, Hartono (2022) found that using augmented reality (AR) in physics learning in high school is able to improve student learning outcomes. Augmented Reality (AR) allows students to understand physical concepts better because they can see and experience firsthand the simulation of the laws of motion and force.

Ibrahim, et al. (2024) found similar results: AR helps students understand force and motion concepts that are usually difficult to understand through textbooks or conventional presentations. Students can expand their understanding of the concepts and apply them to real-world situations through interactive simulations.

AR Use Proven Consistently Effective in Various Education Levels

AR is not only effective in junior and senior high schools, but also in higher education levels such as universities. A study conducted by Rahma et al. (2024) found that the use of AR-based LKPD successfully improved student learning outcomes in junior high school, especially in science learning. This shows that AR is a flexible tool and can be adapted to various subject matter and education levels.

AR Overcomes Visualization Limitations in Physics

One of the biggest advantages of augmented reality (AR) in physics learning is the ability to solve the problem of visualizing abstract concepts. Concepts such as electromagnetic waves, electric fields, or kinetic theory are too abstract to be understood only through textbooks, so students cannot directly see the physics phenomena they are studying. According to Affifah et al. (2020) and Wulandari et al. (2022), AR greatly helps students understand kinetic theory and geometry optics. These two physics subjects are considered difficult by many students. Students more easily understand, remember, and apply physics concepts after seeing these concepts.

The analysis of the grouped materials reveals that most research focuses on the high school level, demonstrating a strong interest in enhancing student outcomes at more advanced educational stages. Meanwhile, To address the accessibility and inclusivity challenges of implementing Augmented Reality (AR) in education, particularly in junior high schools and under-resourced areas, several solutions are proposed. First, developing AR applications compatible with low-specification devices, such as basic smartphones or tablets, can make this technology accessible to schools in remote areas or with limited budgets (Verykokou et al., 2021). Tailoring AR content to align with different educational stages, from junior high to senior high school, ensures it meets students' cognitive abilities and curriculum requirements (AlGerafi et al., 2023; Alkhabra, 2023). Introducing AR technology early in the learning process can familiarize students with its applications and benefits (Iatsyshyn et al., 2020). Expanding the diversity of AR content to include a broader range of subjects and advanced physics topics is also crucial to maximizing its potential. Additionally, comprehensive teacher training programs are essential to equip educators with the skills to effectively integrate AR into their lessons, combining it with innovative teaching strategies (Mystakidis, 2021). Collaboration between educators, researchers, and developers is necessary to create engaging and relevant AR content aligned with educational standards (Penuel et al., 2020). Finally, implementing pilot programs in diverse school settings to test and refine AR applications based on feedback ensures that the technology is effective and practical for both students and teachers. These efforts collectively aim to harness AR's potential to enhance student motivation and learning outcomes while overcoming the barriers of accessibility and inclusivity.

CONCLUSION

The systematic analysis of 20 journals highlights the significant potential of Augmented Reality (AR) to enhance students' motivation and learning outcomes in physics education. AR's capability to visualize abstract concepts and create engaging, interactive learning experiences addresses many challenges associated with traditional teaching methods. However, several barriers hinder its implementation, including limited infrastructure in underdeveloped areas, a lack of teacher expertise in using AR, and the need for more diverse and advanced AR content. To overcome these challenges, it is essential to develop AR applications compatible with low-specification devices to ensure accessibility in schools with limited resources. Additionally, targeted and continuous teacher training should be provided to equip educators with the necessary skills to effectively integrate AR into their lessons. Collaborations between educators and developers are also crucial to expanding AR content to include more advanced physics topics. Furthermore, AR applications should be designed to minimize cognitive overload by gradually introducing complex concepts and complementing traditional teaching methods. Lastly, long-term studies are needed to evaluate the sustained impact of AR on learning outcomes and motivation across various educational levels and environments. By addressing these issues, AR can become a transformative tool in making physics education more inclusive, engaging, and impactful.

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