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A Systematic Review of the Effectiveness of Mobile Learning Tools in Enhancing Physics Education

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Abstract. Mobile learning tools have emerged as a promising approach to enhance physics education by providing interactive, hands-on learning experience. This systematic review examined the effectiveness of mobile learning tools in improving students' learning outcomes in physics education. Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, a comprehensive literature search was conducted, yielding 41 studies that met the inclusion criteria. The selected studies were analyzed using comparative, thematic, and content-analysis techniques. The findings revealed that mobile learning tools, including augmented reality (AR) systems, virtual reality (VR) and mixed reality systems, mobile learning and management systems, educational software and apps, and specialized tools and platforms, are commonly used to teach various physics topics. The effectiveness of mobile learning tools is evident in six key themes: enhanced conceptual understanding, increased engagement and motivation, improved academic performance, the development of higher-order thinking skills, hands-on learning and practical skills, and reduced cognitive load. However, the integration of mobile learning tools into physics instruction faces challenges, such as technical difficulties, high costs, lack of teacher and student expertise, pedagogical integration issues, distractions, and environmental limitations. This study recommends enhancing device compatibility and software stability, providing comprehensive training for teachers and students, aligning tools with existing curricula, promoting wider access to mobile technology, and designing focused learning experiences to prevent cognitive overload. Further research is encouraged to explore the long-term effects of mobile learning on physics education outcomes and to investigate strategies for adapting these tools to diverse student needs and learning environments.

Keywords: Academic Performance; Augmented Reality; Educational Software; Hands-On Learning Mobile Learning; Physics Education; Virtual Reality

1. Introduction

Educational technology has become increasingly important in higher education, including physics education. The use of technology in physics teaching can significantly improve student learning when properly aligned with the teaching aims and fully embedded within a module (Turney et al. 2009). Specifically, Physics Education Technology (PhET) simulations have shown promise in enhancing physics education. A study of Grade 12 STEM students found that PhET Simulation-Integrated instruction improved students' proficiency levels in the least mastered competencies in General Physics 1. The use of PhET simulations in a virtual laboratory to assess student performance in demonstrative applications is particularly effective. Furthermore, integrating PhET simulations into physics lessons promotes positive and engaging learning experiences among students (Rhandy et al. 2024). Similarly, Kotluk and Kocakaya (2017) highlighted the potential of the digital innovative approach to enhance students' academic achievement, self-efficacy, and attitudes toward physics concepts.

Physics education faces unique challenges owing to the abstract nature of concepts, need for expensive laboratory equipment, and difficulties in simulating certain experimental conditions (Cai et al., 2016). Mobile learning tools and augmented reality (AR) technologies offer promising solutions to these challenges in physics education. Augmented reality and motion-sensing technologies can improve students' learning attitudes and outcomes in physics, as demonstrated in a study on the teaching of magnetic fields to eighth-grade students (Cai et al. 2016). Mobile devices and apps can provide innovative ways to enhance science learning by allowing students to access information, make sense of it, and create products with rich visual representations (Castek & Beach, 2013). These tools can help students acquire disciplinary literacies unique to science, particularly when guided by skilled teachers who can exploit the affordances of mobile apps for learning (Castek & Beach, 2013).

Mobile learning tools also offer flexible and interactive environments that address the challenges faced by traditional physics teaching methods. For example, conventional classroom approaches may struggle to effectively convey abstract concepts, but mobile platforms such as PhET simulations and virtual labs provide interactive models that make these ideas more tangible and easier to grasp (Susilawati et al., 2022). These tools allow students to conduct virtual experiments, manipulate models, and revisit difficult materials, thereby supporting self-paced learning and improving their retention. These tools also provide a more accessible way to demonstrate phenomena that are difficult to showcase in physical classrooms (Bernacki et al., 2020).

Furthermore, mobile devices and applications offer significant benefits in terms of enhancing student engagement and comprehension. The flexibility of mobile learning enables students to learn at their own pace, which is a crucial factor in mastering the often-difficult concepts of physics (Khasawneh et al., 2023). Interactive apps and simulations help students visualize and manipulate abstract ideas, such as forces and electricity, making these topics more relatable and easier to understand (Wijaya et al., 2021). This approach not only improves comprehension but also increases motivation and interest in the subject. Additionally, mobile tools encourage collaboration among students through shared platforms, fostering teamwork and problem-solving skills (Khasawneh et al., 2023) while providing immediate feedback that helps learners quickly address gaps in understanding (Wijaya et al., 2021).

Despite the growing adoption of mobile learning in education, systematic research is needed to evaluate its effectiveness, particularly in physics education. This study sought to systematically review and synthesize existing literature on the use of mobile learning as a tool to enhance physics teaching. It aims to address key questions such as identifying the most commonly used mobile learning tools in physics, evaluating their effectiveness in improving student outcomes, and exploring the challenges and limitations of integrating mobile learning into physics instruction. The findings provide valuable insights for students, teachers, and educational institutions by offering strategies to enhance physics teaching and learning. Additionally, this study serves as a foundational resource for future research by highlighting gaps in the current literature and suggesting areas for further investigation.

Statement of the Problem

The main objective of this study is to examine mobile learning as a tool for enhancing physics through a systematic examination and synthesis of information from various studies. Specifically, it aimed to answer the following research question:

1. What are the types of mobile learning tools most commonly used in physics education?
2. What is the effectiveness of mobile learning tools in improving student learning outcomes?
3. What are the key challenges and limitations to integrating mobile learning with physical instruction?

2. Methodology

2.1 Research Design

This study utilized a qualitative research design that adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). PRISMA systematically identifies, screens, and selects studies for review, thereby enhancing the quality and credibility of results (Liberati et al., 2009). This ensured an accurate and thorough literature review. Following the

PRISMA framework, the review process was transparent and comprehensive, encompassing four stages: identification, screening, eligibility determination, and final inclusion.

Table 1. PRISMA Guidelines

Data Collection	Results
Identification Stage	A thorough literature search was conducted using Boolean operators to refine results and capture relevant studies. Specific keywords and phrases such as "mobile learning," "tools," "physics education," and "educational technology" were employed. For example, the query "mobile AND learning AND tools AND physics" targeted studies on mobile learning tools in physics education. The search spanned two major academic databases, Scopus and Wiley Online Library, known for their extensive peer-reviewed collections. A total of 163 studies were retrieved from Scopus, and 34,750 from Wiley Online Library.
Screening	In the screening stage, abstracts of identified articles were reviewed for relevance to the study's objectives, focusing on mobile learning tools in physics education. Studies not aligning with this focus or lacking details on mobile learning were excluded. Key tools reviewed included: Educational Apps: Applications like Khan Academy and Duolingo offer interactive lessons in various subjects. Specifically, apps like Physics Toolbox enable students to conduct simple experiments using mobile devices, promoting hands-on learning. Virtual Labs and Simulations: tools such as PhET Interactive Simulations provide virtual experimental environments, allowing students to explore complex physics concepts interactively and visually, which is often challenging in traditional classrooms. Mobile Learning Platforms: Platforms like Moodle and Google Classroom provide access to course materials, assignments, quizzes, and communication tools via mobile devices, facilitating interaction between students and teachers and supporting both individual and collaborative learning. E-books and Digital Resources: E-books and digital resources available for download on mobile devices offer access to textbooks, research papers, and multimedia content, enabling flexible learning. Digital physics textbooks allow students to study topics like quantum mechanics or thermodynamics anywhere. Studies and articles from 2015 onwards were considered in Wiley Online Library, resulting in 1635 retrieved records, and 123 documents were found in Scopus.com.
Eligibility Determination	During the eligibility stage, the full texts of studies that passed the screening were retrieved and subjected to a more detailed evaluation. Each study was assessed according to specific criteria to ensure that only high-quality and pertinent studies were included in the final review. The eligibility criteria were as follows:

	Population: Studies involving physics students or educators as primary subjects. Intervention/Exposure: The use of mobile learning tools such as educational apps, simulations, or virtual labs, specifically within the context of physics education. Outcomes: This study examined the effectiveness of these tools in improving learning outcomes, such as student engagement, understanding of physics concepts, and overall academic performance. Study Characteristics: Only peer-reviewed empirical studies were considered, ensuring the methodological rigor and credibility of the findings. Studies that did not meet these criteria, such as those focusing on other disciplines or theoretical discussions without empirical data, were excluded from the final review. At this stage, 30 studies were considered from the Wiley Online Library, and 45 studies from Scopus.com were assessed.
Final Inclusion	In the final inclusion stage, a total of 23 articles from Wiley Online Library and 18 articles from Scopus.com met all the specified criteria and were selected for detailed analysis. The review process was documented using a PRISMA Flow Diagram (Figure 1), which visually represented each step from identification to inclusion. The selected articles were then analyzed thoroughly, and the findings were synthesized to address the study's research objectives.

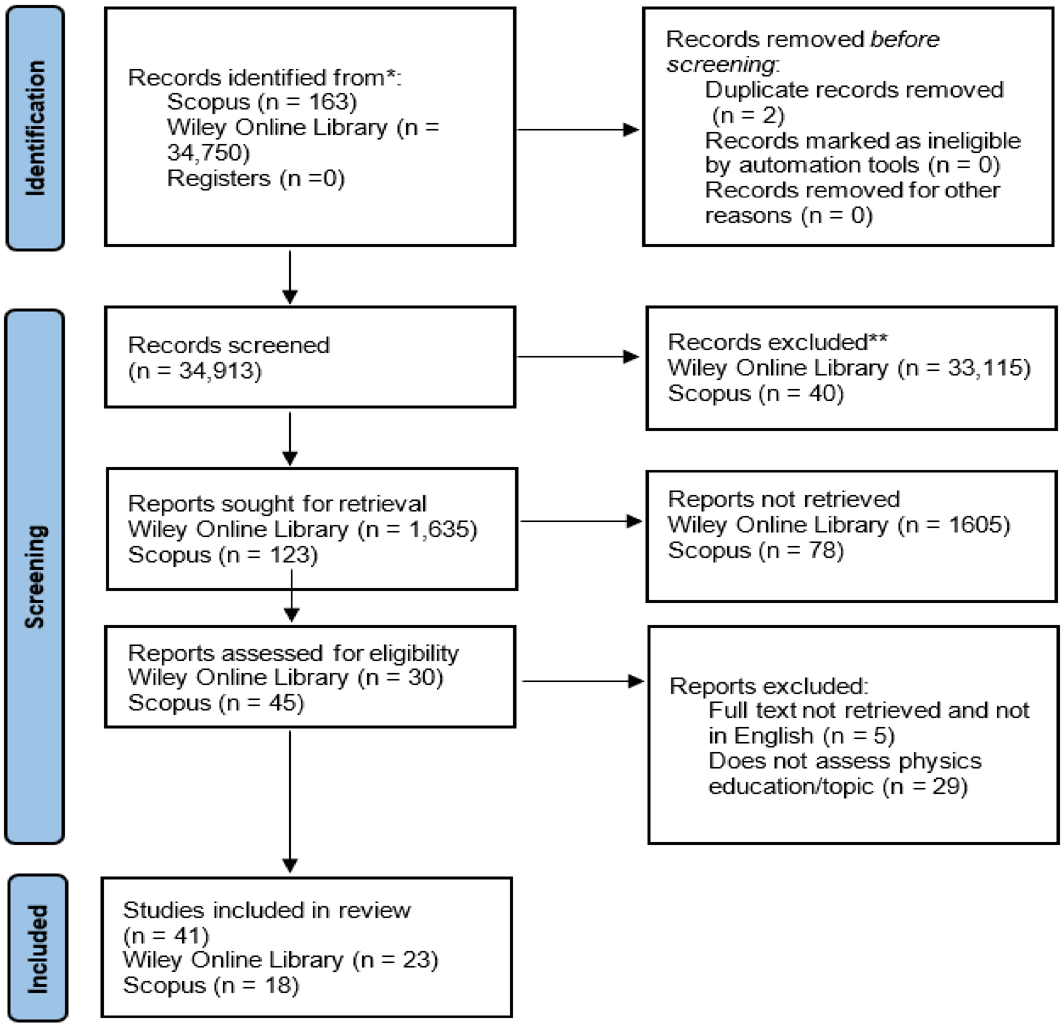

Figure 1. PRISMA Methodology

2.2 Data Analysis

Data from the selected studies were analyzed using comparative, thematic, and content analysis techniques. Comparative analysis identified similarities and differences across studies, clarifying trends and unique insights related to the effectiveness of mobile learning tools in physics education (Miles et al., 2014). This approach examines how tools such as simulations, mobile apps, and learning platforms influence student outcomes in various settings. Thematic analysis identified recurring themes and patterns within the data (Braun & Clarke, 2006), focusing on core themes such as student engagement, conceptual understanding, and challenges in integrating mobile learning in physics instruction. This method organizes data into meaningful categories to enhance the clarity of the findings. Content analysis systematically codes and categorizes data and assesses the frequency and significance of specific concepts and trends (Krippendorff, 2018). By quantifying key elements, such as the types of mobile learning tools used and their reported effectiveness, content analysis evaluated how often these tools were employed and their impact on improving students' performance in physics education.

3. Results and Discussion

3.1 The data present the Mobile learning tools that are most used in physics education

Table 2 presents a categorized overview of various mobile learning tools and applications used in physics education as identified in the reviewed studies. These tools are grouped into five main categories: Augmented Reality (AR) Systems, Virtual Reality (VR) and Mixed Reality Systems, Mobile Learning and Management Systems, Educational Software and Apps, and Specialized Tools and Platforms. Each category includes examples of specific tools or applications employed to enhance physical learning.

Category	Author(s) and Year	Mobile Learning App/Tool	Number of Studies
Augmented Reality (AR) Systems	Barraza Castillo et al. (2015)	Mobile Augmented Reality (pARabola)	10
	Reyes-Aviles & Aviles-Cruz (2018)	Handheld Augmented Reality System (Android)	
	Singh et al. (2019)	Augmented Reality Learning Environment (ARLE)	
	Faridi et al. (2021)	Augmented Reality Learning Environment (ARLE)	
	Liu et al. (2020)	Augmented Reality (AR) based Experimental Tool	
	Sánchez-Obando & Duque-Méndez (2023)	Augmented Reality Mobile App (Unity/Vuforia)	
	Giancaspro et al. (2024)	Augmented Reality (AR) App – "Dist Forces"	
	Miguel Nunes et al. (2024)	ARPocketLab (Augmented Reality)	
	Arymbekov et al. (2024a)	Augmented Reality (Mobile AR app)	
	Arymbekov et al. (2024b)	Augmented Reality (AR) applications	
Virtual Reality (VR) and Mixed Reality Systems	Zatarain-Cabada et al. (2023)	FisicARtivo (AR/VR web-based tool)	2
	Pirker et al. (2017)	Mobile VR (Samsung Gear VR), Room-Scale VR (HTC Vive)	
Mobile Learning and Management Systems	Zhai et al. (2018)	1:1 Mobile Technology (Tablets with Learning Management System)	3
	Zhai et al. (2019)	Mobile Devices with multi-functional apps	
	Minichiello et al. (2021)	Mobile Instructional Particle Image Velocimetry (mI-PIV)	
Educational Software and Apps	Othayoth et al. (2017)	RoboAnalyzer software	17
	Arnay et al. (2017)	Unity3D and Python interactive 3D models	
	Bøe, Henriksen & Angell (2018)	ReleQuant web-based learning resources	

	Menon et al. (2020)	Exploring Physics App (iPad-based)	
	Cai et al. (2021)	AR-based Wave-particle Duality app (AROSE)	
	Minichiello et al. (2021)	Mobile Instructional Particle Image Velocimetry (mI-PIV)	
	Ng (2022)	Flight Simulation Software	
	Laurens Arredondo & Valdés Riquelme (2022)	Google Science Journal App	
	Zhan et al. (2021)	IRobotQ3D (Robotics simulation platform)	
	Purba et al. (2019)	U-Physics app	
	Purba et al. (2024)	Smart-Physics App	
	Kock, Martins & Dias (2023)	Automated Guided Vehicle (AGV)	
	Wang et al. (2022)	Mobile platform-based app for Biomechanics	
	Ferrarelli & Iocchi (2021)	Programming Mobile Robot for Experiments	
	Curto Prieto et al. (2019)	Kahoot	
	Dasilva et al. (2019)	Android-based Interactive Physics Mobile Learning Media (IPMLM)	
	Liu et al. (2017)	InduLab, Smartphones, Lego Mindstorms NXT, Digital Video Cameras	
Specialized Tools and Platforms	Castilla & Peña (2023)	Jupyter Notebooks	9
	Cherifi et al. (2023)	Low-cost ESP32-based platform	
	Onyema et al. (2023)	Smartphones, Laptops, PDAs, Zoom, Mobile Apps	
	Abenes et al. (2023)	Science-Inclusive Gamified Mobile Application (SIGMA)	
	Schweinberger et al. (2023)	Eye tracking Feedback Tool	
	Bilson et al. (2024)	Physics-Informed Machine Learning Modelling	
	Hochberg et al. (2020)	Video Analysis apps on tablets	
	Kuhn et al. (2016)	Google Glass, Tablet PC	
	Aydın & Genç (2016)	Java Applets, Simulation Tools	
Total			41

The Table highlights the diverse range of mobile learning tools integrated into physics education. Augmented Reality (AR) systems are widely used to visualize abstract physical concepts in a more interactive and engaging manner. Tools like the "pARabola" and "ARPocketLab" allow students to explore physics principles through hands-on simulations, enhancing their understanding of complex phenomena. Similarly, Virtual Reality (VR) and Mixed Reality tools, such as "FisicARtivo," create immersive environments where learners can engage in physics experiments that may not be possible in a traditional classroom setting. In addition to AR and VR, mobile learning and management systems such as tablets integrated with learning platforms are common. These systems provide access to course materials, quizzes, and interactive simulations, thereby promoting flexible and personalized learning experiences. Educational software, such as the "Exploring Physics App" and other interactive 3D models, also enable students to explore physics concepts dynamically, which supports active learning.

Table 3. Physics topics addressed through mobile learning tools

Table 3 categorizes the physics topics commonly addressed through mobile learning tools, such as mechanics, electricity, electromagnetism, and quantum physics. For example, tools like "RoboAnalyzer" and "IRobotQ3D" focus on kinematics and mechanics, helping students understand topics like motion, force, and Newton's laws through interactive models and simulations. In contrast, apps like the "Augmented Reality Learning Environment" (ARLE) or the "Maroon VR Lab" tackle complex topics in electricity and electromagnetism, such as resistive circuits, electromagnetism, and wave-particle duality, providing students with detailed, visual representations of these phenomena.

Mechanics and Kinematics		**Number of Studies**
Author(s) and Year	**Physics Topic/Subject**	**12**
Othayoth et al. (2017)	Robot Kinematics, Mechanics	
Arnay et al. (2017)	Robotics – Kinematics	
Laurens Arredondo & Valdés Riquelme (2022)	Kinematics	
Sánchez-Obando & Duque-Méndez (2023)	Physics - Motion (Kinematics)	
Zatarain-Cabada et al. (2023)	Kinematics and Dynamics	
Kock, Martins & Dias (2023)	Newton's Law, Torque, Force, Trigonometry	
Ferrarelli & Iocchi (2021)	Newtonian physics (First Law, Second Law, Superposition principle)	
Liu et al. (2017)	Various physics topics (Kinematics, Pendulum motion, etc.)	
Wang et al. (2022)	Human Kinematics in Biomechanics	
Ng (2022)	Aerodynamics and Flight Principles	
Minichiello et al. (2021)	Fluid Mechanics	
Zhan et al. (2021)	Robotics, 3D simulation	
Electricity and Electromagnetism		
Author(s) and Year	Physics Topic/Subject	9
Reyes-Aviles & Aviles-Cruz (2018)	Resistive Electric Circuits	
Avilés-Cruz & Villegas-Cortez (2019)	Digital Electronics, Logic Gates (Boolean algebra)	

Singh et al. (2019)	Electronics Laboratory Equipment (Oscilloscope, Function Generator)	
Faridi et al. (2021)	Electromagnetism, Maxwell's Equations, DC motor, Generator	
Arymbekov et al. (2024)	Electromagnetism, Optics	
Abenes et al. (2023)	Electricity (MELCs: Voltage, Current, Resistance, Power)	
Pirker et al. (2017)	Electromagnetism (Maroon VR Lab)	
Aydın & Genç (2016)	Hysteresis loop, Semiconductor behavior, Monte Carlo methods	
Liu et al. (2020)	Magnetic field	
Quantum Physics and Advanced Topics		
Author(s) and Year	**Physics Topic/Subject**	
Bøe, Henriksen & Angell (2018)	Quantum Physics	7
Cai et al. (2021)	Optics, Wave-Particle Duality	
Castilla & Peña (2023)	Advanced Fluid Mechanics (FM)	
Giancaspro et al. (2024)	Distributed Forces, Free-body Diagrams, and Rigid Body Equilibrium	
Nunes et al. (2024)	Physical State Changes, Material Density	
Arymbekov et al. (2024)	Nuclear Physics	
Bilson et al. (2024)	RF-EMF exposure in 5G Massive MIMO Systems	
General Physics and Various Topics		
Author(s) and Year	**Physics Topic/Subject**	
Zhai et al. (2018)	General High School Physics	13
Zhai et al. (2019)	High School Physics (general)	
Menon et al. (2020)	Various Physics Topics (e.g., Electricity, Force, and Motion)	
Purba et al. (2019)	Physics (Various Phenomena)	
Purba et al. (2024)	Physics (Inclined Plane Experiments)	
Onyema et al. (2023)	General Physics Topics	
Dasilva et al. (2019)	Various Physics Topics	
Schweinberger et al. (2023)	Physics Experiments (shadows, light)	
Curto Prieto et al. (2019)	Physics & Chemistry	
Hochberg et al. (2020)	Pendulum Movements	
Kuhn et al. (2016)	Acoustics	
Cherifi et al. (2023)	Fundamental Physics (Pendulum, Inclined Plane)	
Barraza Castillo et al. (2015)	Quadratic Equations (Mathematics)	
Total		41

Mechanics and kinematics were the most frequently explored topics in the 12 studies. These studies investigated how mobile learning tools help students visualize and manipulate concepts such as force, motion, and Newton's laws. Tools like "RoboAnalyzer" and simulation platforms were shown to be effective in explaining complex mechanics, including robot kinematics and Newtonian physics. Notable examples include Othayoth et al. (2017), who explored robotic mechanics, and Ferrarelli and Iocchi (2021), who focused on foundational physics principles and demonstrated the versatility of mobile apps in enhancing their understanding through interactive simulations.

Electricity and electromagnetism were examined in nine studies, focusing on tools like the "Augmented Reality Learning Environment" (ARLE) to explore circuits, electromagnetism, and wave-particle duality. Studies such as those by Reyes-Aviles and Aviles-Cruz (2018) on resistive circuits and Faridi et al. (2021) on Maxwell's equations and electromagnets highlight how mobile learning aids in understanding both fundamental and applied concepts in electromagnetism using augmented reality to improve comprehension.

Quantum physics and other advanced topics such as RF-EMF exposure and 5G technologies were covered in seven studies. These studies, including Bøe et al. (2018), explored how mobile learning environments help in teaching complex and abstract concepts such as wave-particle duality. Giancaspro et al. (2024) contributed by focusing on mechanical equilibrium, catering to advanced learners and demonstrating the potential of mobile apps for higher-level physics education. General physical topics including pendulum movements, light, and acoustics were discussed in 13 studies. These studies, such as those by Zhai et al. (2018) and Menon et al. (2020), demonstrate how mobile tools offer flexible and interactive ways to learn foundational physics concepts. Mobile applications cover a wide range of subjects, making physics more accessible and engaging to students at all levels.

In summary, the integration of mobile learning tools across these topics demonstrates their broad potential for enhancing student understanding and engagement in physics education. From basic mechanics to advanced quantum physics, mobile apps, AR, and VR systems provide interactive, hands-on learning experiences that make abstract concepts more accessible.

3.2 Effectiveness of mobile learning tools in improving students' learning outcomes

Table 4 presents a thematic analysis of the effectiveness of mobile learning tools in enhancing students' learning outcomes in physics education. The identified themes included enhanced conceptual understanding, increased engagement and motivation, improved academic performance, the development of higher-order thinking, hands-on learning and practical skills, and reduced cognitive load. These themes reflect the various ways in which mobile learning tools contribute to student success by addressing complex physical concepts and fostering an interactive and engaging learning environment.

The findings presented in Table 4, derived from 12 studies, demonstrate that mobile learning tools substantially enhanced students' comprehension of intricate physical concepts by offering interactive, visual, and practical experiences. In the field of robot kinematics, programs such as RoboAnalyzer facilitate better understanding through interactive diagrams and three-dimensional models (Othayoth et al., 2017; Arnay et al., 2017). For fluid mechanics, a mobile app utilizing particle image velocimetry improves instruction and learning through design-based research methodologies (Minichiello et al., 2021). In the realm of electromagnetism, magnetic experimental tools employing augmented reality boost students' understanding, while decreasing their mental workload (Liu et al., 2021). Virtual reality applications, such as Maroon VR, deliver full-scale physics lab experiences and make abstract ideas more concrete (Pirker et al., 2017). Notably, topics such as Newtonian physics have seen improvements through robot experiment programming (Ferrarelli & Iocchi, 2021), whereas advanced fluid mechanics concepts are better understood using interactive Jupyter notebooks (Castilla & Peña, 2023). Overall, these mobile learning tools enhance critical thinking skills and learning outcomes in physics (Faridi et al. 2021), surpassing traditional methods by providing immersive, interactive, and tailored learning experiences that accommodate various learning styles and increase engagement with complex physical phenomena.

This study identified ten study tools that fostered increased engagement, satisfaction, and motivation to learn, especially through interactive and hands-on learning experiences in physics education. Specific topics that show improved understanding through mobile learning include complex physics problem visualization (Aydin & Genç, 2016), digital electronics (Avilés-Cruz & Villegas-Cortez, 2019), kinematics (Arredondo & Riquelme, 2021), and physics experiments using smart glasses (Kuhn et al., 2016). Augmented reality applications have proven particularly effective in enhancing didactic methodologies in physics education (Arymbekov et al., 2024b; Sánchez-Obando & Duque-Méndez, 2023). The use of mobile technology-based physics curricula also positively affects pre-service elementary teachers' technology self-efficacy (Menon et al., 2020). These innovative approaches not only facilitate a better understanding of complex physics concepts, but also provide more engaging and interactive learning experiences than traditional methods, especially in contexts such as rural schools and during the COVID-19 pandemic (Ng, 2022; Sánchez-Obando & Duque-Méndez, 2023).

Eight studies were identified that showed notable enhancements in academic outcomes, particularly in exam results and inquiry-based learning behaviors in Physics Education, through the utilization of mobile and augmented reality technologies. Purba and Hwang (2024) emphasized the significance of instructor feedback in U-physics exploration activities, whereas Purba et al. (2019) illustrated the beneficial impacts of ubiquitous physics applications on learning accomplishments in real-world settings. Abenes et al. (2023) noted improved scholastic performance in eighth-grade physics classes by using gamified mobile applications. Certain topics that are more effectively comprehended through mobile learning compared with conventional methods include distributed forces (Giancaspro et al., 2024), resistive electric circuits (Reyes-Aviles & Aviles-Cruz, 2018), and various high school physics concepts (Zhai et al., 2018). Research also indicates that mobile technologies and augmented reality systems boost student involvement, offer interactive learning experiences, and aid in a better understanding of abstract physics concepts. Furthermore, Onyema et al. (2023) explored the influence of mobile technology and big data in physics education during the coronavirus lockdown, suggesting that these tools can be especially effective in remote learning environments.

These results identified five papers that demonstrated that mobile learning tools have significantly enhanced physics education by promoting critical thinking, problem-solving, and scientific modeling abilities. Research has shown that these tools can boost students' higher-order thinking skills (HOTS) and confidence in physics (Cai et al., 2019; Cai et al., 2020). Certain areas of physics, such as experimental analysis using video tools and multiple representations, benefit particularly from mobile learning as they reduce cognitive burden and improve comprehension (Hochberg et al., 2020). Furthermore, student-driven and collaborative aspects of mobile technology have been found to positively influence physical achievement and interest (Zhai et al., 2019). In physics education, augmented reality applications have been shown to enhance student self-efficacy and learning perceptions (Cai et al., 2020). These findings indicate that mobile learning tools can serve as effective supplements to conventional teaching methods in physics education, especially in areas that require visualization, experimentation, and interactive engagement.

This study identified four additional studies that highlighted how educational tools enhance practical learning and the application of theoretical knowledge in physics education. These studies highlight the efficacy of innovative approaches in improving students' real-world understanding of physics concepts. Wang et al. (2022) created a smartphone application for biomechanics education, focusing on human kinematics, which enhanced students' ability to apply theoretical concepts to practical scenarios. Cherifi et al. (2023) developed an affordable ESP32-based platform for teaching fundamental physics, offering hands-on experience in areas such as mechanics, thermodynamics, and electromagnetism. Schweinberger et al. (2023) employed eye-tracking technology as a feedback mechanism in physics teacher education, providing insight into visual attention patterns during problem-solving tasks. Curto Prieto et al. (2019) evaluated the effectiveness of Kahoot in science and mathematics education, noting improved student engagement and comprehension. Mobile learning is particularly beneficial for understanding topics, such as human kinematics, basic physics principles, and various aspects of science and mathematics. These educational tools offer interactive features, immediate feedback, and visualization capabilities, making abstract concepts more accessible and comprehensible than conventional teaching methods.

The findings from two additional studies provide further evidence of how mobile tools alleviate students' cognitive burden and facilitate their comprehension of intricate physics concepts. In particular, mobile applications incorporating augmented reality (AR) have demonstrated considerable promise in easing the cognitive load and improving the understanding of complex physics principles. Singh et al. (2019) revealed that AR-based learning environments enhance engineering students' proficiency in electronics laboratories, indicating that AR tools can effectively connect theoretical knowledge with practical applications. Similarly, Liu et al. (2020) observed that AR-based magnetic experimental tools positively influenced students' knowledge acquisition, while decreasing their cognitive load in physics education. Areas that have particularly benefited from mobile learning include electromagnetic theory, circuit analysis, and magnetic-field visualization. These investigations suggest that mobile tools, especially those employing AR technology, can deliver interactive, immersive experiences that render abstract physical concepts more tangible and accessible than conventional teaching approaches.

Themes	**Author(s) - Number of Authors**		**Description of Themes**
Enhanced Conceptual Understanding	Barraza Castillo et al. (2015), Othayoth et al. (2017), Arnay et al. (2017), Faridi et al. (2021), Zhan et al. (2021), Ferrarelli & Iocchi (2021), Minichiello et al. (2021), Liu et al. (2021), Castilla & Peña (2023), Bilson et al. (2024), Bøe, Henriksen & Angell (2018), Pirker et al. (2017)	12	Mobile learning tools improved students' understanding of complex topics such as quadratic equations, robot kinematics, electromagnetism, fluid mechanics, and biomechanics.
Increased Engagement and Motivation	Aydın & Genç (2016), Avilés-Cruz & Villegas-Cortez (2019), Menon et al. (2020), Ng (2022), Laurens Arredondo & Valdés Riquelme (2022), Arymbekov et al. (2024), Kock, Martins & Dias (2023), Sánchez-Obando & Duque-Méndez (2023), Zatarain-Cabada et al. (2023), Kuhn et al. (2016)	10	Tools fostered increased engagement, satisfaction, and motivation to learn, especially through interactive and hands-on learning experiences.
Improved Academic Performance	Purba et al. (2019), Purba et al. (2024), Abenes et al. (2023), Giancaspro et al. (2024), Nunes et al. (2024), Reyes-Aviles & Aviles-Cruz (2018), Onyema et al. (2023), Zhai et al., (2018)	8	Significant improvements in academic performance, especially in test scores and inquiry-based learning behaviors.
Development of Higher-Order Thinking	Dasilva et al. (2019), Cai et al. (2021), Liu et al. (2017), Zhai et al. (2019), Hochberg et al. (2020)	5	Mobile learning tools helped develop critical thinking, problem-solving, and scientific modeling skills.

Hands-on Learning and Practical Skills	Wang et al. (2022), Cherifi et al. (2023), Schweinberger et al. (2023), Curto Prieto et al. (2019)	4	Tools provided hands-on experience and practical learning, improving students' ability to apply theoretical knowledge to real-world situations.
Reduced Cognitive Load	Singh et al. (2019), Liu et al. (2020)	2	Mobile tools helped reduce the cognitive load for students, making complex concepts easier to understand.

The findings highlight the transformative impact of mobile learning tools on physics education, demonstrating their ability to enhance students' comprehension of complex concepts through interactive, visual, and hands-on experience. Tools such as RoboAnalyzer and Jupyter notebooks facilitate understanding of topics such as kinematics and fluid mechanics, while augmented reality (AR) applications, such as Maroon VR, and gamified apps improve engagement, motivation, and academic performance. These technologies bridge theoretical knowledge with practical applications, particularly in challenging subjects, such as electromagnetism, distributed forces, and circuit analysis. Research emphasizes their effectiveness in fostering critical thinking, problem-solving, and scientific modelling skills while reducing cognitive load and increasing accessibility in remote and under-resourced settings. Overall, mobile and AR-based tools surpass traditional methods by delivering immersive and personalized learning experiences, enhancing both learning outcomes and student satisfaction.

3.3 Key challenges and limitations of integrating mobile learning with physical instruction

Table 5 presents the thematic analysis of the key challenges and limitations that arise when integrating mobile learning tools with physical instruction. The identified themes included technical challenges, cost and access limitations, teacher and student expertise, pedagogical integration, distraction and cognitive overload, and lighting and environmental conditions. These themes highlight various difficulties encountered in the effective use of mobile learning tools in educational settings.

Technical difficulties were a significant limitation in 12 studies, with issues such as device limitations, software glitches, Bluetooth connectivity, and instability frequently arising in the AR/VR technologies. These problems hinder the functionality of mobile learning tools, making them difficult to consistently use in classroom environments. Ten studies also highlighted high costs, limited access to AR/VR devices, and expensive data plans as barriers to mobile learning, exacerbating the digital divide. Moreover, ten studies noted a lack of technical expertise among teachers and students, further impeding the effective use of mobile learning tools. Integrating these tools with traditional teaching methods also posed challenges; eight studies observed difficulties in balancing student-driven learning with teacher-guided instruction. In addition, three studies mentioned distractions caused by recreational mobile device use and information overload, which could lead to cognitive fatigue and hinder learning. Environmental factors, such as lighting, also affected the usability of mobile tools, as identified in two studies.

Themes	**Author(s) - Number of Authors**		**Description of Themes**
Technical Challenges	Barraza Castillo et al. (2015), Othayoth et al. (2017), Singh et al. (2019), Liu et al. (2020), Zhan et al. (2021), Cherifi et al. (2023), Wang et al. (2022), Aydın & Genç (2016), Arnay et al. (2017), Ng (2022), Nunes et al. (2024), Bilson et al. (2024)	12	Issues related to device limitations, software glitches, Bluetooth connectivity, high costs, and stability of AR/VR technologies.
Cost and Access Limitations	Minichiello et al. (2021), Faridi et al. (2021), Giancaspro et al. (2024), Abenes et al. (2023), Pirker et al. (2017), Onyema et al. (2023), Arymbekov et al. (2024a), Schweinberger et al. (2023), Hochberg et al. (2020), Liu et al. (2017)	10	High cost of hardware/software, limited access to AR/VR devices, data costs, and accessibility issues for some students.
Teacher and Student Expertise	Barraza Castillo et al. (2015), Zhai et al. (2019), Cai et al. (2021), Zatarain-Cabada et al. (2023), Castilla & Peña (2023), Bøe, Henriksen & Angell (2018), Laurens Arredondo & Valdés Riquelme (2022), Sánchez-Obando & Duque-Méndez (2023), Arymbekov et al. (2024b), Dasilva et al. (2019)	10	Lack of programming or technical skills among teachers and students, limited confidence in using mobile learning tools, and need for technical training.
Pedagogical Integration	Zhai et al. (2018), Menon et al. (2020), Zhai et al. (2019), Ferrarelli & Iocchi (2021), Curto Prieto et al. (2019), Kuhn et al. (2016), Purba et al. (2024), Purba et al. (2019)	8	Challenges in fully integrating mobile tools with traditional teaching methods, balancing student-driven vs. teacher-driven learning, and alignment with curricula.
Distraction and Cognitive Overload	Zhai et al. (2019), Curto Prieto et al. (2019), Kuhn et al. (2016)	3	Students may become distracted by recreational use of devices or experience cognitive overload from excessive information and unfamiliar tools.
Lighting and Environmental Conditions	Reyes-Aviles & Aviles-Cruz (2018), Avilés-Cruz & Villegas-Cortez (2019)	2	Lighting conditions affected the use of mobile tools, especially for image recognition or low-light environments.
N/A (Not explicitly discussed	Kock, Martins & Dias (2023)	1	Challenges not discussed

Despite these challenges, this analysis addresses cognitive load as a potential challenge in mobile learning for physics education, and proposes several strategies to minimize cognitive overload in mobile learning tools. These strategies include chunking information, progressive disclosure, multimedia integration, adaptive learning, clear user-interface design, guided exploration, immediate feedback, customizable settings, offline access, and collaborative features. By breaking complex physics concepts into manageable units, gradually introducing information, using diverse media, adjusting content difficulty based on student performance, and providing intuitive interfaces, these tools can enhance the learning experience. In addition, offering scaffolding, real-time feedback, personalized settings, offline functionality, and peer learning opportunities can further reduce cognitive strain. Implementing these design principles can help balance the complexity of physical concepts with usability, ultimately improving the effectiveness of mobile learning in physics education settings. Addressing these limitations through training, improved access, and thoughtful curriculum integration are essential for successful implementation. By overcoming these obstacles, mobile learning tools can significantly enhance physics education.

4. Conclusions and Recommendations

This study investigated the impact of mobile learning tools on physics education outcomes, focusing on their effectiveness in enhancing students' learning experiences and academic performance. The research findings demonstrate that mobile learning tools significantly improve conceptual understanding, engagement, academic performance, and higher-order thinking skills in physics education, particularly in mechanics and kinematics. These tools offer interactive and personalized learning experiences, making complex physical concepts more accessible and engaging for students. Despite the evident benefits, the study also identified challenges, such as technical issues and high implementation costs, which need to be addressed for widespread adoption. The key takeaways from this research emphasize the importance of improving device compatibility, developing affordable tools, implementing comprehensive training programs for educators and students, and aligning mobile learning tools with the existing curricula. To maximize the potential of these tools, it is crucial to establish clear usage guidelines, design focused learning experiences, and conduct long-term research to assess their sustained impacts. Furthermore, collaboration among stakeholders, including educators, developers, and policymakers, is essential for addressing the digital divide and ensuring equitable access to these educational resources. As mobile learning tools continue to evolve, maintaining a balance between teacher-guided instruction and student-driven learning will be critical in harnessing their full potential to revolutionize physics education and extend their benefits to other STEM disciplines.

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