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Contextualizing technology in physics education: Systematic insights into trends, patterns, and gaps (2014-2024)

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Abstract Currently, the technology integration into physics education is quickly expanding. However, there has been little systematic study on the role of contextual methods and digital technologies in building effective, relevant, and sustainable learning processes. This study systematically examines trends, patterns, and research gaps in contextual technology-based physics learning over the past decade to provide a scientific roadmap to guide the development of future educational pedagogy and technology. This study employs a Systematic Literature Review (SLR) technique that follows the PRISMA 2020 recommendations. The literature search process was carried out systematically through two highly reputable databases, namely, Scopus and Springer, because both provide access to high-quality, peer-reviewed international publications and cover multidisciplinary fields of education, science, and technology. Additional quantitative analysis was conducted through bibliometric visualization, including coauthorship networks, cocitation analysis, and bibliometric mapping using VOSViewer, to map the relationships between authors, articles, and dominant keywords. This analysis discovered 3,973 publications, with just 16 making it to the final selection step. The results show the dominance of augmented reality-based approaches, virtual labs, and contextual multimedia in developing countries like Indonesia. However, there is a lack of studies using longitudinal, cross-national collaborative, and AI-based approaches in an exploratory local context. This study presents a critical synthesis of contextual technology approaches in physics education while identifying theoretical and methodological gaps and providing directions for further evidence-based and contextual research. Teachers and learning designers are advised to develop physics teaching tools that integrate local cultural contexts and high-interaction-based technologies such as AR/VR and engage students in real-life project-based exploration.

Keywords: scientific roadmap, critical synthesis, local cultural contexts, augmented reality, systematic literature review

1. Introduction

Over the past decade, information and communication technologies (ICTs) have significantly transformed the way individuals learn and acquire information. This is particularly true with the emergence of new interactive technologies in education (Øverup, 2024; Vidak et al., 2024). Numerous studies have shown that digital platforms are becoming increasingly prevalent in international education (Li et al., 2025). This aligns with the imperative for physics education to incorporate digital components, thus categorizing them as essential to the learning process, not merely enhancements (Arymbekov & Turekhanova, 2025; Zhao, 2025). Physics education, previously defined by expository techniques and conceptual abstraction, now faces the need to meet the needs of the digital native generation, which demands meaningful, interactive, and contextual learning experiences (Volodin et al., 2025). Figure 1 illustrates the research trends leading to the development of learning innovations. These innovations combine contextual elements such as local knowledge, virtual environments, and experiential learning with augmented reality, virtual reality, or other digital technologies to facilitate the teaching of difficult subjects such as physics.

Figure 1 shows that participants in physics education research over the previous decade, from 2014--2024, are categorized into several interconnected clusters, with augmented reality and science education at the center, demonstrating strong links with several other topics. These links illustrate the broad scope of research that integrates technology and innovation into science education, particularly physics. Physics is a fundamental subject of natural science and is based on principles that govern all events (Park et al., 2019). Therefore, physics education in the digital age requires the use of contextual learning integrated with technology to enhance its relevance. A network visualization study was conducted to examine specific links within the domain of physics education and physics learning, as shown in Figure 2.

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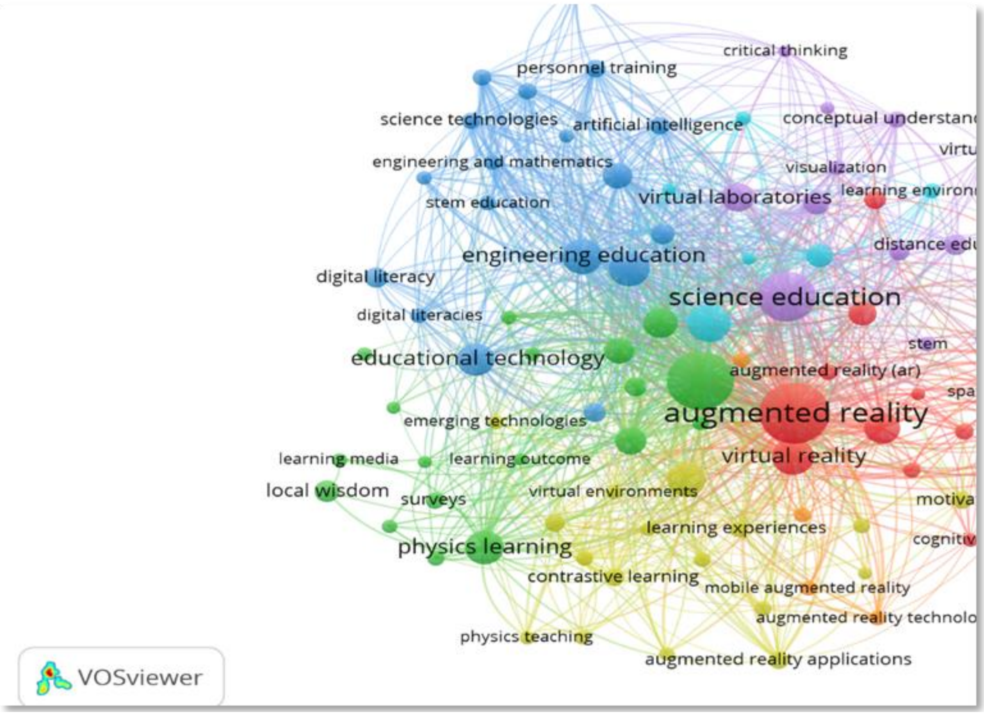

Figure 1 Physics education research over the last decade. *Source:* Vosviewer.

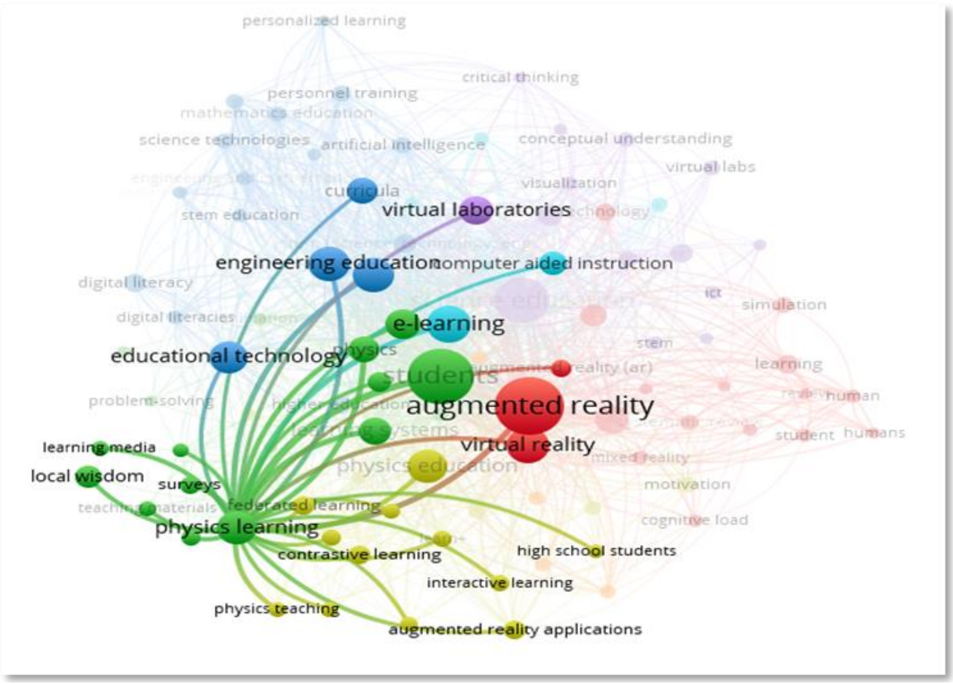

Figure 2 Physics education and learning network. *Source:* Vosviewer.

Figure 2 shows a visualization of the physics education and physics learning topic network. The keywords have a network map with augmented reality and educational technology occupying a central position with high connectivity to other keywords. This visualization indicates that current physics learning research is developing strongly in the integration of technology to support the level of complexity of physics experienced by students. Physics learning is inherently complex because it involves characteristics that are rich in symbols, formulas, and abstract concepts, which are not always easy for students to understand (Thees et al., 2020). When physics concepts are presented without linking them to students' daily lives, the process of internalizing meaning becomes weak (Cai et al., 2021), and learning outcomes tend to be low (Nurussaniah & Setyosari, 2024; Rahmat et al., 2024). Therefore, the application of a contextual approach is a pedagogical necessity to enable students to understand physics holistically and relevantly (Altmeyer et al., 2020). This approach allows students to build understanding through direct experience, problem-solving activities, and exploration of real phenomena related to daily life (Yu et al., 2023).

The use of technology in learning serves as a crucial cognitive mediator (Sung et al., 2019). Simulation software, augmented reality (AR), virtual laboratories, and the use of inexpensive sensors, as well as interactive web-based and mobile applications, have been widely developed to visually and dynamically represent physics concepts (Chu, 2022). Technology serves as a bridge connecting abstract representations with concrete experiences, enabling students to observe, manipulate, and evaluate physical phenomena in a more flexible and personalized learning environment (Sun et al., 2023). Despite numerous studies demonstrating positive outcomes from technology integration in physics education, its effectiveness varies (Lai & Cheong, 2022). Many factors can influence the success of technology-based learning innovations, ranging from teachers' readiness to use technology pedagogically to the availability of infrastructure and devices (Bogusevschi & Muntean, 2020).

In addition, there has been significant growth in scientific papers about technology in physics education over the past ten decades, both in terms of the number of scientific papers and the number of different themes they cover (Ropawandi et al., 2022). Nonetheless, this research is frequently disjointed and lacks systematic organization, complicating the formulation of cohesive conclusions on advancements in this domain (Arymbekov & Turekhanova, 2023). It is still difficult to determine the direction of progress, methodological trends, and research gaps without a full systematic review. Most current investigations appear to be confined, insufficiently diffuse, and deficient in robust theoretical contributions (Sahin & Yilmaz, 2020; Arici et al., 2021). Conversely, the predominant research methodologies are characterized by small-scale experimental designs, lacking the equilibrium provided by longitudinal analysis or comprehensive evaluative frameworks (Strzys et al., 2018). The contextual factor, which is meant to improve students' comprehension and learning, is sometimes not given enough attention or may be overlooked completely when technology is being used (Moriello et al., 2022).

Current educational requirements underscore the need for systematic research that can critically and objectively describe trends, patterns, and gaps in the scientific literature related to technology-based contextual physics learning (Kapp et al., 2020). This research is crucial not only for scientific purposes but also for developing more effective, relevant, and flexible educational interventions that respond to current demands (Arymbekov et al., 2023). Without a thorough understanding of the current research landscape, innovation in physics education can be disjointed and unsustainable. This aligns with the function of systematic literature reviews as a significant instrument of epistemological reflection, ensuring that educational activities are grounded in a robust theoretical and empirical framework rather than functioning in isolation. This technique allows researchers to reassess prevailing thematic biases, challenge dominant methodological assumptions, and create opportunities for exploring new perspectives in developing truly contextual and technology-based learning models (Grivokostopoulou et al., 2017).

Both the Transforming Education agenda and the Sustainable Development Goals (SDGs) call for innovative approaches to education that integrate real-world situations with technological tools (Cai et al., 2013). Enyedy et al. (2012) state that modern science education, and physics education in particular, is anticipated to generate graduates who are not only academically proficient but also socially sensitive, equipped with 21st-century abilities, and able to handle real-world issues in a sustainable way. The crucial aspect here is the incorporation of technological solutions with contextual methods (Ateş, 2025).

The local context is essential to this study, since the technology utilized in educational institutions is inextricably linked to the sociocultural background, infrastructure, and pedagogical preparedness of each nation or area (Komalawardhana & Panjaburee, 2024). Consequently, it is essential to ascertain not only the subject of the study but also the location, the researchers involved, and the contextual framework in which the research is undertaken. This study will enhance global discourse and aid in the democratization of knowledge within science education (Akçayır & Akçayır, 2017). This research seeks to analyze the perspectives, tactics, and issues encountered by educators in the integration of technology into learning. This systematic review is directed by the key research question: How have trends, patterns, and research gaps in contextually oriented, technology-based physics education changed from 2014--2024?

This study follows the subquestions to address this inquiry thoroughly:

• Q1: What are the trends and advancements in the incorporation of digital technologies in physics education during the last ten years?

• Q2: What are the attributes and impacts of contextual technologies, including augmented reality, virtual labs, and digital simulations, in facilitating physics education?

• Q3: What elements affect the efficacy of contextual technology-based physics education, such as educator preparedness, institutional backing, and device accessibility?

• Q4: What are the geographic gaps and sociocultural contexts in the implementation of technology?

This study synthesizes the methodological trends, conceptual contributions, and practical implications of the integration of contextual technology into physics learning. This analysis is expected to clarify the direction of developing learning models that are not only responsive to technological developments but also sensitive to the diverse contexts of student learning. Additionally, it enhances the theoretical underpinnings of physics education and offers an empirical basis for formulating educational policy, curriculum design, and teacher training programs focused on the effective integration of technology. This project aims to facilitate the creation of an inclusive, contextually equitable, and technology-driven physics learning environment that is both ethical and sustainable.

1.1. Digital technology integration in physics education

Over the past decade, the integration of digital technology in physics learning has progressed rapidly, in line with the increasing need for education relevant to Industrial Revolution 4.0 and Society 5.0. Previously, physics learning was still conventional, lecture-based, and focused on physics laboratory experiments, but now, it has evolved into contextual, interactive, and personalized digital platform-based learning. Technological innovations, including augmented reality (AR), virtual laboratories, artificial intelligence (AI), adaptive e-modules, and generative platforms, have emerged. This opens new possibilities in facilitating students' understanding of abstract and complex physics concepts.

AR applications in science education significantly improve students' mathematical creativity and conceptual understanding (Hidajat, 2023). In the physics context, this technology is very effective for visualizing phenomena that are difficult to observe directly, such as waves, magnetic forces, or parabolic motion. Furthermore, the use of virtual laboratories allows for the replacement or supplementation of physics laboratory experiments in schools with limited resources (Reyes et al., 2024; Shambare & Jita, 2024). Therefore, virtual laboratories allow students to conduct physics experiments in a safe simulation environment, characterized by high interactivity and time flexibility.

This is in line with Astalini et al. (2024), who stated that digital media can foster argumentation skills, persistence, and curiosity in the context of physics learning. This finding reinforces the view that technology is not only a tool but also a pedagogical strategy that can develop students' scientific attitudes. This conclusion is supported by Chang & Kidman (2023) and Kim et al. (2024), who showed that TPACK is the dominant framework used to examine teacher readiness in integrating technology into physics learning. In this context, teachers' professional development effectively enhances their capacity to create meaningful digital learning experiences.

On the other hand, generative AI approaches are beginning to enter the realm of physics education. A study by Alneyadi and Wardat (2024) demonstrated that AI can be used as a learning partner to support high school students in understanding physics. This opens up opportunities for the use of dialog-based models, personalized learning, and problem solving through artificial intelligence in advanced physics. In addition to strengthening physics content, the trend toward integrating digital technology also aims to support the development of social and contextual competencies. Denga and Denga (2024) as well as Jenny and Kiruthiga (2025) suggest that technology should not only be used to improve academic performance but also serve as a means of fostering values, empathy, and sustainability through real-world physics learning.

However, the integration of digital technology in physics education has shifted from merely adapting devices to implementing context-based pedagogical innovations tailored to the needs of the digital generation. This development requires teachers to be actively involved in designing TPACK-based learning strategies and promoting interdisciplinary collaboration to make physics a contextual, creative, and relevant science capable of addressing the challenges of the 21st century.

1.2. Contextual technology implementation in physics learning

Over the past decade, the use of technology in physics education has grown rapidly, particularly with the increasing emphasis on connecting science education to the real world. The implementation of contextual technology is no longer seen simply as the use of digital devices but rather as an effort to build more authentic and meaningful learning environments that foster deep conceptual understanding. Recent studies highlight the importance of integrating context-based technology into physics education to bridge the gap between theoretical knowledge and practical applications in daily life.

A physics curriculum based on an interdisciplinary approach and context-based learning is crucial for enhancing students' cognitive and affective competencies (Yalçin and Sadik, 2024). This finding indicates that when physics learning is connected to real-world contexts, such as everyday phenomena or interdisciplinary challenges, students not only gain a deeper understanding of physics concepts but also develop greater interest and more positive attitudes toward the subject.

Advances in immersive technologies such as virtual reality (VR) and augmented reality (AR) have opened new opportunities for creating realistic and interactive physics learning simulations. Giancaspro et al. (2023) asserted that the use of AR in teaching vector mechanics allows students to explore forces, acceleration, and motion in three-dimensional space. Marshall et al. (2024) also demonstrated the effectiveness of using VR simulations in a nuclear radiology laboratory environment, which can be directly applied in a nuclear physics context. This technology helps visualize abstract concepts and increases student engagement in the learning process.

The impact of technology on differentiated physics instruction allows teachers to tailor their teaching approaches to individual student needs (Sofi-Karim et al., 2022). This finding reinforces the previous findings of Abd Rahman et al., (2026), who evaluated the use of tutoring-based learning tools and ICT for elementary school students. These results indicate that contextual technology can be an effective tool for bridging the gap in understanding of student levels in heterogeneous classrooms.

Flexibility in designing learning situations is also a concern in the context of contextual technology. Garau et al., (2024) discussed the application of the flexible learning itinerary configurator (FLIC) to design learning scenarios in elementary education. Although this study does not directly focus on physics, the flexible design it offers is relevant for developing context-based physics learning, particularly in designing virtual experiment modules or project-based learning assignments tailored to students' environments.

Previous research has demonstrated the development of virtual laboratories and remote experiments as a contextual approach to physics concepts. Nelke et al., (2024) described the integration of the Internet of Things (IoT) in STEM education, enabling remote experiments. This approach supports the principles of affordability and accessibility in physics education, especially for students in areas with limited physics laboratory resources. Moreover, implementing technology also requires teacher readiness, both in terms of knowledge and cognitive structure. Tschönhens et al. (2024) highlighted how the TPACK framework helps teachers, both trainees and experienced teachers, align the use of technology with physics teaching materials and pedagogical strategies. Furthermore, research by Shambare and Simuja (2024) offers an overview of the challenges and evolution of physics teacher pedagogy in rural areas, where technology integration is implemented contextually, taking into account infrastructure constraints.

The design and interaction aspects are also important focuses in contextual technology-based learning. Müller et al. (2023) emphasized the importance of designing interactive public displays in educational environments and creating community-based and collaborative learning spaces. This aligns with the perspective of Bally et al. (2024), who explain through an ethnographic approach that explores the relationships between students, teachers, and digital artifacts, emphasizing that successful technology integration depends not only on the tools used but also on the social meanings constructed around them. Furthermore, Qi (2024) explains the effective impact of contextual technology-based physics learning and that positive experiences in technology-based learning environments can mediate students' social anxiety and increase their emotional engagement. This evidence strengthens the argument that the success of technology implementation lies not only in cognitive aspects but also in how students emotionally connect with the physics learning process.

Finally, contextual technology implementation in physics education opens up significant opportunities for innovation. Technology is not only a visualization tool but also a catalyst for immersive, adaptive, and relevant learning experiences that align with students' daily lives. The challenge ahead remains how to build a physics education system that can synergistically integrate technology, context, and pedagogy to create a holistic learning experience.

1.3. Implementation of technology-based contextual learning

The integration of digital technology into contextual learning requires teachers to possess high pedagogical competencies to design adaptive and meaningful learning (Gerard et al., 2015; Kim et al., 2024). Pedagogical competency plays a crucial role in the process of personalized technology-based learning, particularly in the development of contextual learning strategies, approaches, and models (Stringer et al., 2023). However, significant challenges, such as low digital literacy and a lack of professional training, hinder teachers' implementation of technology-assisted context-based learning (Consoli et al., 2024).

Teachers lacking pedagogical skills and an understanding of local contexts often struggle to adapt digital technology to the curriculum, resulting in a lack of relevance to students' learning environments (Sharifuddin & Hashim, 2024). Furthermore, limited infrastructure and curriculum incompatibility are often major obstacles, particularly in schools lacking access to digital resources (Stringer et al., 2023). Therefore, teachers' pedagogical competence must include the ability to analyze students' social contexts, select appropriate technology, and develop flexible problem-based learning approaches (Dong et al., 2026).

Previous research has shown that the use of contextual technology can improve students' motivation, conceptual understanding, and critical thinking skills if teachers are able to adapt their teaching approaches to student characteristics and the learning environment (Chu et al., 2025). However, teachers still face challenges in developing digital teaching materials, particularly in students' local contexts and cultures, due to time constraints and a lack of relevant training. Furthermore, teachers must be able to design technology-based assessments that measure not only learning outcomes but also students' thinking processes in solving contextual problems (Semeraro et al., 2023; Nisa' & Suprapto, 2024).

The application of technology in contextual learning requires teachers to master technology, pedagogy, and content in a balanced manner, as outlined in the TPACK framework (Zou et al., 2024). Furthermore, continuous professional development for teachers is crucial for improving pedagogical competence and supporting innovation based on contextual technology.

The description above demonstrates that a local context-based and technology-based learning approach can enhance students' understanding of the social environment and strengthen 21st-century skills such as collaboration and critical thinking. Therefore, strengthening teachers' pedagogical competence in contextual technology applications is a basis for creating adaptive, relevant, and meaningful learning in the digital age.

1.4. Geographical disparities and socio-cultural contexts in technology-based contextual learning implementation

Numerous studies have confirmed that geographic disparities, particularly between urban and rural areas, are significant barriers to the adoption of educational technology. Chang & Kidman (2023) reported in his systematic review that the digital divide prevents rural schools from optimally accessing learning technology because of limited infrastructure, teacher training, and technical support. This finding reflects the reality experienced in many developing countries. Although technological tools such as virtual laboratories and augmented reality are available, their availability is uneven, and their use has not been maximized in rural areas.

Furthermore, Giannini & Bowen (2022) identified structural and cultural barriers to digital learning during the COVID-19 pandemic. These findings revealed that students in rural areas face the dual challenge of unstable network systems and social norms that limit access to technology, especially for female students. This work provides strong evidence that the technology gap is not simply a technical issue but also relates to the complexities of local social and cultural contexts that must be considered when designing technology-based learning.

Conversely, in urban areas, despite better access to technology in terms of infrastructure, challenges arise in the form of institutional pressures and professional isolation, which impact the quality of technology implementation. Jogezai et al. (2021) reported that physics teachers in both urban and rural areas experience barriers to professional collaboration, which significantly impacts the technology integration process. While this study is not specific to physics, it is relevant in the context of implementation patterns of science-based educational technology.

On the other hand, Liarokapis et al. (2024) explored teacher interactions in rural areas via extended reality (XR). This study revealed that when teachers received hands-on training and actively participated in the design of an XR app, their understanding and contextual adaptation of the technology improved. These findings suggest that involving local actors in the design and training process can enhance the cultural relevance and effectiveness of technology in physics.

Thus, this study highlights that geographic and sociocultural gaps in educational technology integration are multidimensional. Infrastructure challenges, such as internet and device connectivity in rural areas, coupled with sociocultural barriers such as gender norms, teacher training quality, and professional isolation, create complex limitations in contextual technology implementation. The success of technology interventions is not solely determined by the sophistication of the device but is highly dependent on the local context and the active participation of local educational stakeholders.

2. Materials and Methods

Research exploration related to contextual technology implementation in physics learning was conducted through a systematic literature review covering publications from 2014--2024. This review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines (Page et al., 2021). The PRISMA 2020 guidelines were used to ensure the accuracy and effectiveness of the review process. Several key components were considered, including the primary research question, study and participant characteristics, the type of intervention or technological approach implemented, the outcome variables studied, and the research methodology used. These components were systematically designed to anticipate and manage potential variations in study design and results during the selection and analysis process. Page et al. (2021) emphasized that the PRISMA 2020 guidelines can improve transparency, reliability, and methodological accuracy in systematic review results.

2.1. Search strategies

The literature search employed three systematic strategies: identification, screening, eligibility, and inclusion. The search was conducted via the Scopus and Springer E-Journal databases as the basis for this research. This is because both are the world's leading scientific databases, encompassing international publications from various disciplines. To obtain relevant and focused results, the following keywords were used: ("digital technology" OR "educational technology" OR "technology integration" OR "ICT" OR “augmented reality" OR "virtual laboratory" OR "virtual lab" OR "digital simulation" OR "interactive simulation.") AND (“physics education" OR "physics learning.”) AND ("teacher readiness" OR "teacher competence" OR "digital literacy" OR "teacher preparation.") AND (“local wisdom" OR "ethnoscience" OR "ethnophysics. ").

A literature search was conducted to facilitate the identification of articles from each database on the basis of the combination of Boolean keywords used. The search results are shown in Table 1. These articles were screened using inclusion and exclusion criteria to ensure their relevance to the research objectives.

This screening stage aims to eliminate irrelevant articles. Therefore, inclusion and exclusion criteria were established during the process of selecting appropriate studies for analysis and synthesis. This phase also ensures the quality and relevance of the selected studies, as well as maintaining objectivity in decision-making on the basis of available evidence (Smela et al., 2023). These criteria focus on the discussion of contextual technology-based physics learning. Table 2 displays the inclusion and exclusion criteria.

Table 2 shows that the article search and selection process for this study was carried out systematically through several filtering stages according to predetermined criteria. The initial database search yielded a total of 3,973 articles on the basis of keywords. Several articles were eliminated through the filtering stage until 16 articles were determined to be suitable for analysis. This filtering stage reflects a systematic effort to ensure that the analyzed articles are of high quality and relevant to the research focus. These stages follow the PRISMA 2020 guidelines in Figure 3.

Table 1 Search category overview.

Search Categories	Scopus Database	Springer E-Journal Database
Digital Technology Integration in Physics Education	90	537
Contextual technologies for physics	253	1.702
Teachers' competence in implementing technology-based physics learning	34	1.306
Cultural and geographical disparities	43	8

Source: Scopus database.

Table 2 Exclusion-inclusion criteria.

Search criteria	Inclusion	Exclusion
Time Period	Published from 2014 to 2024	Out of period
Accessibility	Open Access	Nonopen access
Document Types	Article and conference paper	Book chapter
Language	English	Other languages
Scopes	Contextual learning-based physics education integrated with digital technology.	Noncontextual
According to the title	Within the scope	Beyond the scope
Research findings	The study is relevant regarding the impact of contextual technology-based physics learning.	Do not report the effects of contextual technology integration in physics learning

Source: Scopus database.

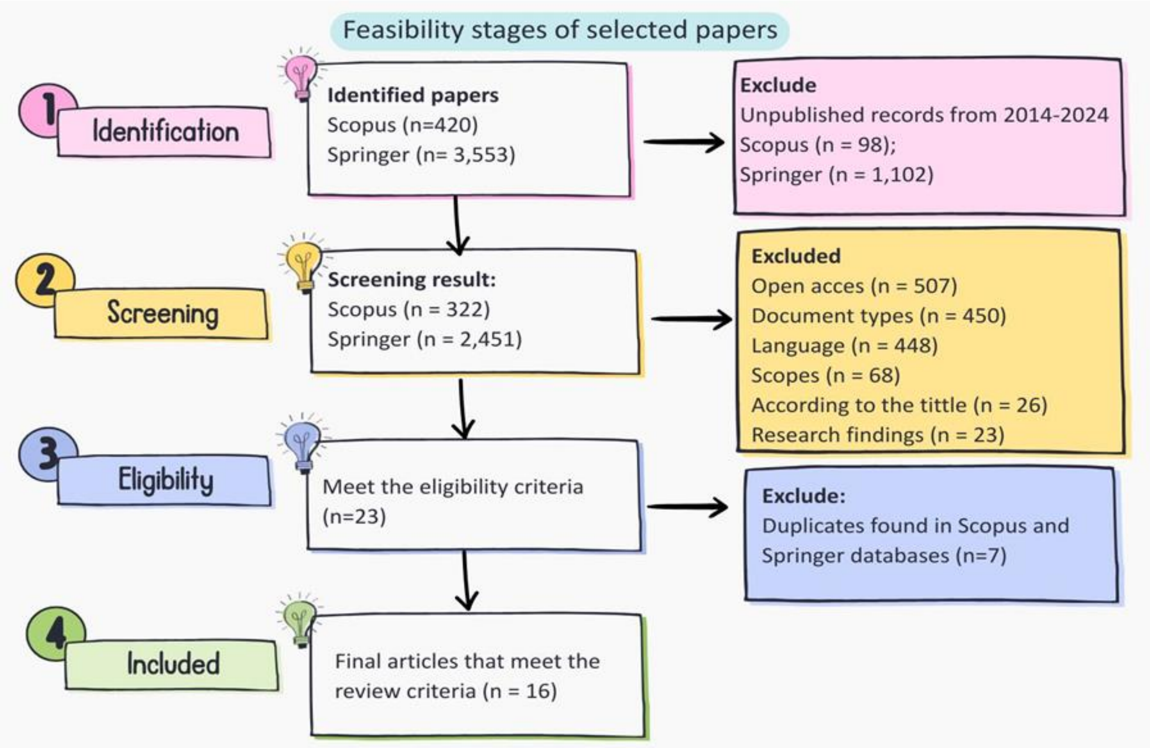

Figure 3 Selection of papers with a PRISMA 2020 diagram. *Source:* Page et al. (2021).

Figure 3 shows the article selection stages in the systematic literature review (SLR) process, which aims to filter out articles irrelevant to the research objectives. The screening process begins with the identification stage, which is designed to find articles that can answer the research questions. This stage identified 3,973 articles: 3,553 from the Springer e-Journal database and 420 from the Scopus database. On the basis of the initial identification, 98 articles from the Scopus database and 1,102 from Springer were excluded because they were outside the specified publication timeframe (2014--2024). This timeframe was established to ensure that research remains up-to-date and relevant (Shaffril et al., 2020). The remaining 2,773 articles qualified for further screening: 322 from Scopus and 2,451 from Springer.

The next stage involved screening on the basis of the inclusion and exclusion criteria described in Table 2. As a result, 23 articles met the eligibility criteria. Finally, in the final stage, articles found to be identical and originating from two different databases or identified as duplicates were excluded. Four articles were excluded because of duplication, leaving 16 articles that passed the screening. These articles were truly relevant, credible, and appropriate studies to answer this research question, which focuses on technology-based contextual physics learning. These studies were then further analyzed for data synthesis and systematic and objective conclusions.

3. Results and Discussion

Figure 4 shows the results of filtering articles on the basis of search keywords. Six documents explicitly address the first research question (Q1). This topic has received considerable attention in previous research. Furthermore, four documents related to the second research question (Q2), indicating a fairly consistent focus on this aspect. The third question (Q3) is supported by one document, indicating that this theme is still rarely explored and could constitute a potential research gap for further study. Five documents contribute to the fourth research question (Q4), demonstrating a relatively high level of interest in this issue. Figure 4 provides additional information on the temporal trends of publications discussing technology-based physics learning in the context of contextual learning.

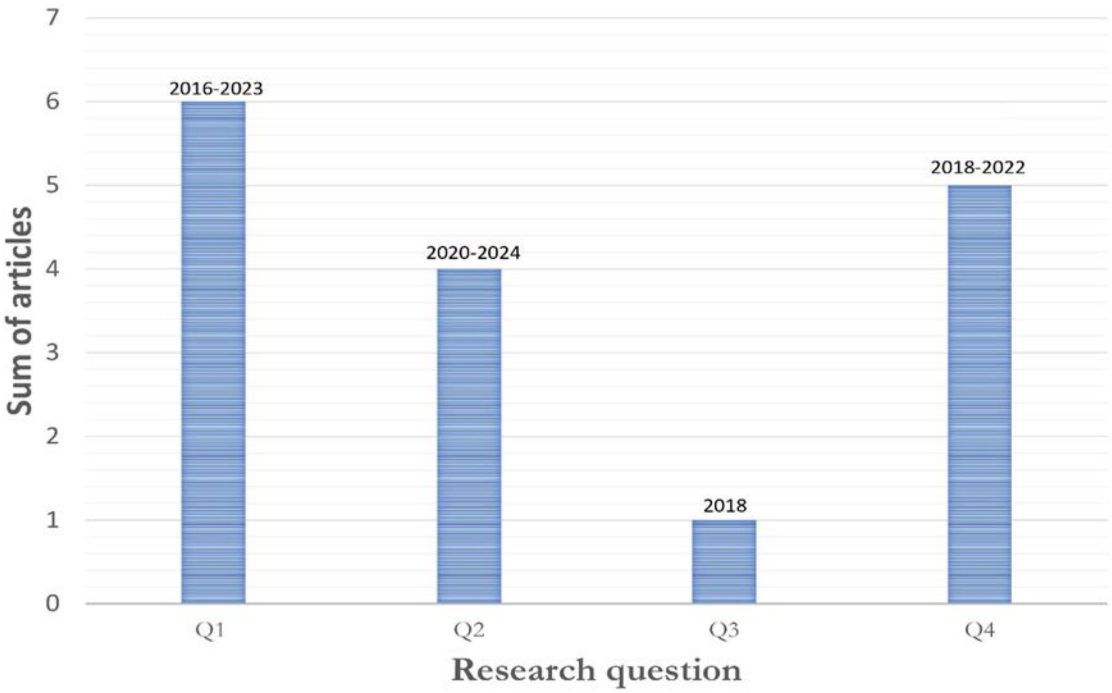

Figure 4 Selected articles for analysis and publication periods. *Source:* Scopus database.

The publication findings for this case show that no articles were published in 2014, 2015, or 2021. The number increased in 2016 and peaked in 2019, 2020, and 2023, with three articles each. This trend indicates that research related to this topic has received increased attention, especially in the past five years. The number of articles also remained relatively stable in 2018, 2022, and 2024, with one to two articles each. These data indicate that interest in this field of study has continued consistently, although it has decreased in certain years. Figure 5 below provides a more comprehensive understanding of the countries of origin of the articles.

Figure 5 displays the geographical distribution of the articles analyzed. The majority of the reviewed articles originated from Indonesia, with 12 documents. This indicates a high level of interest in the topic of contextual technology-based physics learning at the national level. Additionally, the US had two contributions, whereas Vietnam, Australia, Germany, and Slovenia each had one. This distribution indicates that, despite the breadth of the study, the dominant contributions still came from within the country. These results may reflect a strong local context, the relevance of national education policies, or the research focus of Indonesian institutions on the issue under study. However, the predominance of articles originating from Indonesia (12 of 16 publications) with only a few contributions from five other countries (the United States, Vietnam, Australia, Germany, and Slovenia) poses a clear geographic limitation to the reach and generalizability of this review's findings. Therefore, the synthesis in this review primarily reflects the context of physics education research and policy in Indonesia and, more broadly, the Global South, where contextualization efforts are often framed through local wisdom and resource constraints. The patterns identified, such as the predominance of AR-based interventions, the focus on short-term classroom trials, and the strong role of local cultural artifacts, cannot necessarily be assumed to represent technology integration practices in physics classrooms in the Global North, which have very different infrastructures, teacher professional development systems, and curricular traditions (Chang & Kidman, 2023; Giannini & Bowen, 2022; Jogezai et al., 2021; Liarokapis et al., 2024). Therefore, future systematic reviews need to involve a larger and geographically balanced corpus, including the use of multilingual databases, to test the robustness and consistency of these trends beyond the Indonesian and Asian contexts. Table 3 presents further details, including the country of origin of the publication, the author's name, the year of publication, and the title of the article that answers the research question.

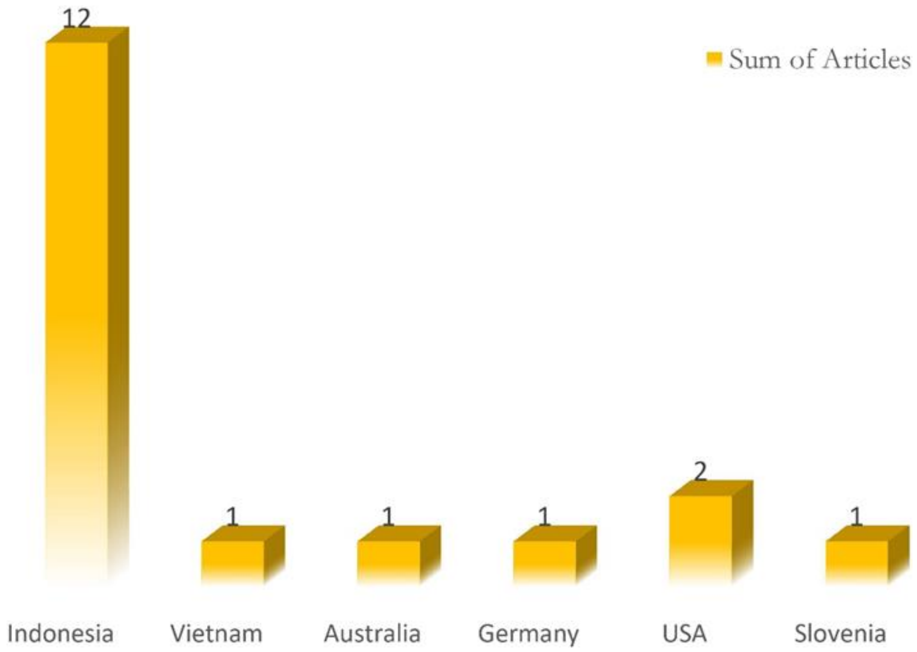

Figure 5 Countrywise Distribution of Publications. *Source:* Scopus database.

Table 3 details the country of origin, author name, year of publication, and article title. This list serves as the basis for identifying the relationship between the analyzed literature and each research question (Q) in this study. Through these data, we can see how contributions from different countries and authors relate to the topic under study while also illustrating the temporal development and diversity of approaches used. This table structure also facilitates the search for primary sources relevant to specific dimensions of technology-based contextual physics education. Table 4 provides a deeper understanding of the content and contribution of each article related to the research question, as it presents a summary of the findings of the analyzed studies.

3.1. Trends and digital technology integration in physics

Over the past decade, the integration of digital technology in physics education has experienced rapid and significant development, both in terms of technology adoption, pedagogical approaches, and the breadth of its application contexts. The shift in the learning paradigm from traditional approaches to context-based digital approaches is influenced by the rapid advancement of information technology, the need for 21st-century competencies, and the significant impact of the COVID-19 pandemic, which has driven the widespread adoption of distance learning (Sharma et al., 2025; Azlan et al., 2020). Over the past decade, publications related to the integration of digital technology in physics education have grown rapidly and significantly, covering technology adoption, pedagogical approaches, and broader applications. The primary focus of these publications has shifted from the use of digital devices to contextual learning strategies that emphasize the development of critical, collaborative, and exploratory thinking skills.

Temporal trend analysis reveals several distinctive developmental phases in bibliometric data and thematic analysis results. In the early years (2014–2018), the primary focus remained on the development of interactive multimedia-based learning media such as videos, PowerPoint presentations, and animations. The contextual learning (CTL) approach began to be integrated with the use of computers and the internet, although its scope has remained limited (Ardiva, 2019; Afradisca, 2019). However, since 2019, there has been a shift toward a more structured and strategic approach, particularly through the development of educational media based on the TPACK framework. Ilmi et al. (2020) and Kim et al. (2024) reported that TPACK improves physics teachers' teaching skills and strengthens digital learning designs focused on developing higher-order thinking skills (HOTS) and scientific attitudes.

The peak of technological acceleration occurred during the 2020–2022 pandemic. The use of learning management systems (LMSs), Android-based simulations, e-modules, and virtual laboratories has become very common. This global crisis has become a pivotal moment in driving widespread digital transformation (Azlan et al., 2020; Sharma et al., 2025). During this time, students began interacting with digital content designed to facilitate exploratory and investigative skills (Sanjaya et al., 2024; Priscilia & Haryani, 2025).

Table 3 Articles analyzed.

Countries	Author/publication year	Title	Question (Q)
Indonesia	Rizki et al. (2023).	Adventuring Physics: Integration of Adventure Game and Augmented Reality Based on Android in Physics Learning	Q1
Indonesia	Ihsan et al., (2019)	Analysis of electronic module development using model inquiry-based learning with approach contextual teaching and learning in physics material of senior high school class X	Q1
Indonesia	Afradisca, (2019).	Development of Learning Media in Circular Motion for Senior High School using ICT based on contextual learning	Q1
Vietnam and Australia	Nguyen and Williams (2016).	An ICT supported sociocultural approach to improve the teaching of physics	Q1
Germany	Laumann et al. (2024)	Analyzing the effective use of augmented reality glasses in university physics laboratory courses for the example topic of optical polarization	Q1
America	Johnson-Glenberg and Megowan-Romanowicz (2017).	Embodied science and mixed reality: How gesture and motion capture affect physics education	Q1
Indonesia	Rahmasari and Kuswanto (2023)	The Effectiveness of Problem-Based Learning Physics Pocketbook Integrating Augmented Reality with the Local Wisdom of Catapults in Improving Mathematical and Graphical Representation Abilities	Q2
Indonesia	Rahmayani, et al. (2024).	Development of e-book integrated augmented reality based on STEM approaches to improve critical thinking and multiple representation skills in learning physics.	Q2
Indonesia	Suprapto, et al. (2020).	An evaluation of the "PicsAR" research project: An augmented reality in physics learning	Q2
Indonesia	Nasir and Fakhruddin (2023).	Design and Analysis of Multimedia Mobile Learning Based on Augmented Reality to Improve Achievement in Physics Learning	Q2
Slovenia and America	Gregorcic et al. (2017).	A new way of using the interactive whiteboard in a high school physics classroom: A case study	Q3
Indonesia	Mudjid et al. (2022).	Development of Android Physics Learning Tools Based on Local Wisdom Traditional Game Bola Boy as a Learning Source	Q4
Indonesia	Sari et al. (2020).	Development of physics comic based on local wisdom: Hopscotch (engklek) game android-assisted to improve mathematical representation ability and creative thinking of high school students	Q4
Indonesia	Setiyadi and Kurniawan, (2020).	Multimedia learning modules (MLMs) based on local wisdom in physics learning to improve student diagram representations in realizing the nature of science	Q4
Indonesia	Naqiyah and Rosana, (2019).	Developing physics learning tools based on local wisdom in the form of musical instrument of gandrang bulo dance as learning source in sound wave	Q4
Indonesia	Husna and Kuswanto, (2018).	Development of Physics Mobile Learning Based on Local Wisdom to Improve Vector and Diagram Representation Abilities	Q4

Source: Scopus database.

In the 2023–2024 academic year, technology-based physics learning approaches are trending toward greater innovation and contextualization. This is evident in several published studies. Rizki et al. (2023) developed an augmented reality (AR)-based educational game to enhance the understanding of physics concepts. Moreover, Herliana et al. (2024) created a web-based inquiry platform to encourage digital scientific exploration. Furthermore, artificial intelligence (AI)-based technologies such as ChatGPT have been explored to facilitate a personalized and adaptive understanding of quantum theory (Alneyadi & Wardat, 2024). This study shows that technology integration encompasses not only media aspects but also intelligent, dialogic, and student-centered learning interaction design. On the basis of the thematic synthesis results, technology integration in physics learning can be classified into five main categories, as shown in Table 5.

Table 4 Findings based on research questions.

Questions	Titles	Findings
Q1	Adventuring Physics: Integration of Adventure Game and Augmented Reality Based on Android in Physics Learning	The integration of adventure games and augmented reality on Android effectively increases student engagement and understanding.
Q1	Analysis of electronic module development using model inquiry-based learning with approach contextual teaching and learning in physics material of senior high school class X	The use of e-modules with an inquiry-based and contextual approach improves students' conceptual understanding.
Q1	Development of Learning Media in Circular Motion for Senior High School using ICT based on contextual learning	ICT-based learning media and contextual learning in circular motion improve student understanding.
Q1	An ICT supported sociocultural approach to improve the teaching of physics	An ICT-based sociocultural approach improves the quality of physics teaching and student participation.
Q1	Analyzing the effective use of augmented reality glasses in university physics laboratory courses for the example topic of optical polarization	The use of augmented reality glasses in physics laboratories effectively improves understanding of polarization optics.
Q1	Embodied science and mixed reality: How gesture and motion capture affect physics education	Mixed reality and motion capture enhance embodied learning and understanding of physics concepts.
Q2	The Effectiveness of Problem-Based Learning Physics Pocketbook Integrating Augmented Reality with the Local Wisdom of Catapults in Improving Mathematical and Graphical Representation Abilities	AR-based pocketbooks and local wisdom effectively improve students' mathematical and graphical representation skills.
Q2	Development of e-book integrated augmented reality based on STEM approaches to improve critical thinking and multiple representation skills in learning physics.	STEM-based AR e-books enhance critical thinking and multiple representation skills.
Q2	An evaluation of the "PicsAR" research project: An augmented reality in physics learning	PicsAR media is effective in improving students' scientific attitudes in physics learning.
Q2	Design and Analysis of Multimedia Mobile Learning Based on Augmented Reality to Improve Achievement in Physics Learning	AR-based multimedia mobile learning improves physics learning outcomes.
Q3	A new way of using the interactive whiteboard in a high school physics classroom: A case study	Interactive whiteboards increase student participation and understanding of physics concepts in high school classrooms.
Q4	Development of Android Physics Learning Tools Based on Local Wisdom Traditional Game Bola Boy as a Learning Source	The Bola Boy traditional game-based Android learning media supports contextual physics learning.
Q4	Development of physics comic based on local wisdom: Hopscotch (engklek) game android-assisted to improve mathematical representation ability and creative thinking of high school students	Traditional hopscotch-based physics comics improve mathematical representation and creative thinking skills.
Q4	Multimedia learning modules (MLMs) based on local wisdom in physics learning to improve student diagram representations in realizing the nature of science	Multimedia based on local wisdom helps students represent scientific diagrams and understand the nature of science.
Q4	Developing physics learning tools based on local wisdom in the form of musical instrument of gandrang bulo dance as learning source in sound wave	Multimedia based on local wisdom helps students represent scientific diagrams and understand the nature of science.
Q4	Development of Physics Mobile Learning Based on Local Wisdom to Improve Vector and Diagram Representation Abilities	Mobile learning based on local wisdom improves students' vector representation and diagramming skills.

Source: Scopus database.

Table 5 shows that this technology functions not only as a tool but also as a context-based learning strategy that directly enriches students' learning experiences. The contexts discussed in digital learning are also increasingly diverse, ranging from global issues such as global warming (Ariani et al., 2024) and disasters (Ayu & Fauzi, 2020) to sustainability literacy (Jenny & Kiruthiga, 2025). Although the integration of digital technology has made significant progress, several challenges and limitations remain. Much research remains experimental and has not yet reached diverse populations. There are also few longitudinal studies evaluating the long-term impact of technology integration in physics education. Furthermore, technology-based physics learning approaches that leverage the local context, culture, and ecology have not been extensively explored, despite their importance in connecting physics to students' real-life experiences (Santoso et al., 2022).

Table 5 Findings based on the research questions.

Technology Category	Learning Function	Study References
Augmented Reality (AR)	Visualization of abstract phenomena increases student motivation and interactivity.	Rizki et al. (2023); Ropawandi et al. (2022)
Virtual Laboratory	Replacing physical lab work, enabling simulation-based experiments, and remote control	Asrizal et al., (2024); Lahme et al. (2023); Reyes et al. (2024)
TPACK-Based Pedagogy	Improving teachers' readiness to integrate technology strategically and pedagogically	Ilmi & Sunarno (2020); Kim et al. (2024); Chang & Kidman. (2023)
AI Generatif & Tutor Digital	Providing dialog-based and adaptive learning support tailored to students' needs	Alneyadi & Wardat (2024); Denga & Denga (2024)
STEM-Integrated Multimedia	Integrating real-world contexts into project-based physics learning and scientific inquiry	Ariani et al. (2024); Herliana et al. (2024); Priscilia & Haryani, 2025)

Source: Scopus database.

Thus, the trends and developments in digital technology integration in physics education over the past decade have demonstrated a transition from basic technological adaptations to more context-rich, interactive, and AI-based pedagogical innovations. Technology is no longer just a tool but a transformative force in how teachers and students perceive and understand physics. This opens up vast opportunities for developing learning models that are more relevant to the realities of the 21st century, but also demands further comprehensive, long-term, and context-based research.

More specifically, the findings of trends in the last decade align with various studies confirming that the integration of digital technology in physics learning is no longer limited to the use of electronic presentations or videos alone but is shifting toward interactive media such as augmented reality, virtual laboratories, and web-based and mobile simulations. Various studies have shown that AR and VR can reduce cognitive load while increasing students' conceptual understanding and emotional engagement in abstract physics labs (Akçayır & Akçayır, 2017; Altmeyer et al., 2020; Thees et al., 2020). Furthermore, the development of LMSs, digital modules, and online learning during the COVID-19 pandemic has expanded the exploration space for inquiry-based physics learning and independent investigation (Azlan et al., 2020; Sharma et al., 2025). The results of this article's synthesis confirm a similar pattern: the majority of reviewed studies position technology as the primary medium for visualizing concepts, facilitating virtual experiments, and stimulating higher-order thinking activities, particularly in developing country contexts like Indonesia, which utilize the Android platform, free simulations, and relatively low-cost AR applications.

However, compared to global trends, the integration of digital technology in physics education in the studies analyzed in this review remains relatively limited to short-term experimental designs and narrow contexts, with a predominance of AR- and simulation-based media approaches without any support from longitudinal studies, cross-country studies, or serious exploration of artificial intelligence as an adaptive tutoring system (Sahin & Yilmaz, 2020; Lai & Cheong, 2022; Li et al., 2025). In fact, several recent literatures show that the success of technology is largely determined by the extent to which it is linked to the learning context, local culture, and explicit pedagogical strategies, such as TPACK, CTL, and ethnoscience/ethnophysics integration (Hartini et al., 2017; Kurniawan, 2021; Utami et al., 2024). This gap confirms that the mapped technology integration trends still tend to be technology-centered and have not yet fully addressed the contextual dimension systematically.

3.2. Contextual technologies for physics

A review of various studies specifically exploring the use of these technologies was conducted to answer the second research question (Q2), concerning the characteristics and contributions of contextual technologies such as augmented reality, virtual laboratories, and digital simulations in supporting physics learning. These studies highlight how contextual technologies provide a more interactive, visual, and contextual approach to learning, enabling students to understand abstract concepts in physics. By utilizing immersive, simulation-based learning environments, these technologies not only bring students closer to real-world representations of physical phenomena but also enhance their cognitive, affective, and psychomotor engagement in the learning process.

The analysis of question Q2 is important because it offers an in-depth assessment of the potential of contextual technologies in redefining how students construct scientific understanding through digital visualization, exploration, and experimentation. Furthermore, these findings underscore the role of technology as a pedagogical medium capable of bridging the limitations of space, time, and resources in physics education while opening up opportunities for personalized and differentiated learning tailored to students' needs, as shown in Table 6.

Table 6 Main findings for research question Q2.

Author(s)/Year	Title/Source Highlight	Technology Used	Objectives/ Focus	Contribution/Results
Rahmasari & Kuswanto (2023)	Local wisdom + AR + physics (Scopus)	Augmented Reality (AR)	Integrating local wisdom and AR for physics learning	Increase students' connectedness to local cultural contexts and conceptual understanding
Rahmayani et al. (2024)	STEM-PjBL + AR + physics (Scopus)	AR + STEM-PjBL	Implementing the AR-based PjBL model in contextual physics learning	Enhancing participation, collaboration, and understanding of physics concepts
Putry (2018)	Local wisdom + Android + physics (Scopus)	Mobile App (Android)	Developing Android-based physics applications with a local wisdom context	Improving motivation and understanding through a culture- and technology-based approach
Ferdiman et al. (2023)	AR in Newton's Law (Scopus)	Augmented Reality	Delivering Newton's laws using AR media	Improving the visualization of Newton's laws, even without an explicit local context
Suprapto et al. (2020)	PicsAR physics media (Scopus)	AR-based Media	Providing interactive PicsAR media for physics learning	Enhancing engagement and understanding of physics concepts through visual experiences
Nasir & Fakhruddin (2023)	Mobile learning on physics (Scopus)	Mobile Learning	Examining the effectiveness of mobile learning in physics learning	Providing flexible access and supporting independent learning
Erviana et al., (2024)	(Springer)	Nonspecific (digital general)	Examining the effectiveness of mobile learning in physics learning	Reported an increase in learning outcomes, even though contextual learning was not explicitly mentioned.
Ferdiman et al. (2023)	(Springer, berbeda sumber)	Augmented Reality (AR)	Analyzing the effects of digital media in physics learning	Improving understanding of Newtonian topics, but not explicit in a contextual approach
Suprapto et al. (2020)	(Springer)	Augmented Reality (AR)	Explaining the use of AR for physics learning	Providing alternative visualizations of physics material
Nasir & Fakhruddin (2023)	(Springer)	Mobile Learning	Developing PicsAR based on digital physics media Researching mobile-based learning on physics topics	Facilitating flexible learning, even though the local context is not mentioned
Nguyen & Williams (2016)	(Springer)	Nonspecific (digital general)	Analyzing technology integration in physics learning	Reporting positive impacts on student learning outcomes, even though they do not explicitly refer to the local context

Source: Scopus database.

The development of digital technology has changed the paradigm of education, including in physics learning, which is known for its complex concepts and difficulties in visualizing abstract phenomena. To address these challenges, various contextual technologies, such as augmented reality (AR), virtual laboratories, and digital simulations, have been integrated into physics education. These technologies enable students to build understanding through interactive, contextual, and authentic representations (Kulaksız & Karaca, 2022; Bekele et al., 2023). In this context, the role of teachers as facilitators of technology-based learning becomes crucial, especially in developing adaptive pedagogical-technological knowledge (Moon et al., 2024; Susanti & Mukminin, 2022). Li et al. (2024) emphasized the importance of teachers' pedagogical and technological readiness (technological pedagogical readiness (TPR)) as a prerequisite for successful technology integration in learning. Therefore, the implementation of contextual technology depends not only on the availability of devices but also on a learning ecosystem that is responsive to the social, cultural, and pedagogical context (Touloukian et al., 2024; Znagui, 2024).

AR technology offers a learning environment that blends the real world with digital objects, enabling students to explore physics concepts spatially, visually, and kinesthetically. In the context of science education, the use of AR has been shown to enhance conceptual understanding, learning motivation, and student interactivity (Hsu et al., 2023; Sondagar et al., 2025). Platforms such as SciAR Labs provide hands-on physics experiment experiences through digital overlays that interact with the real world. Álvarez-Marín et al. (2024) demonstrated that the aesthetic and informational qualities of AR interfaces significantly contribute to student acceptance of this technology. AR applications are also being developed for more complex contexts, such as performing arts-based 3D interaction design and spatial education (Arslan & Berthaut, 2025). Poushneh and Vasquez-Parraga (2024) reported that the level of interaction autonomy and emotional engagement significantly influences the user experience with AR technology. Therefore, AR is not simply a visualization tool but also a pedagogical instrument that encourages active, context-based learning engagement.

Virtual laboratories offer interactive digital environments that simulate science experiments, making them accessible at any time. This overcomes the limitations of physics laboratories in terms of education, including equipment availability, safety risks, and time constraints. Mustari and Nugroho (2025) applied this approach through a MOOC-based virtual laboratory module that allows students to conduct experiments independently and repeatedly, deepening their understanding through a constructivist approach. Griffin et al. (2025) added that while virtual laboratories cannot completely replace face-to-face experiences, they can serve as an important complement to science-based learning. Elbeshbeishy et al. (2025) noted that students in health sciences have positive perceptions of the use of virtual resources, reflecting a similar trend in physics. Cantarelli et al. (2025) reported significant potential for digital laboratories in terms of skills-based and procedural learning. This technology supports learning flexibility, collaboration, cost and time efficiency, which are often barriers in schools.

Digital simulations play a crucial role in developing scientific thinking skills, as they enable the systematic exploration of relationships between variables in real-world contexts. Through simulations, students can test physical laws such as the dynamics of motion, energy, or electric fields in a safe and flexible environment. Fecke et al. (2025) argued that simulations can improve students' scientific communication skills and critical reflection. Bauer et al. (2025) emphasized the importance of personalization in simulation-based learning, where students can independently adjust their learning pace and style. Tsivitanidou et al. (2021) highlighted the contribution of virtual reality-based simulations in enhancing inquiry-based physics learning outcomes and creating meaningful experiences. The use of VR and interactive simulations is also evident in medical and technical training, which can be adapted to physics education (Weimer et al., 2025; Comulada et al., 2025). With this approach, digital simulations not only expand the scope of experiments but also enrich the learning process through exploration, prediction, and testing of scientific hypotheses.

The integration of contextual technology in physics education has wide-ranging implications for curricula, teacher training, and educational policy. Teachers are not only required to master technology but also to design learning experiences that integrate scientific principles with real-life contexts (Kulaksız & Karaca, 2022; Chang & Kidman, 2023). This requires strengthening pedagogical capacity through practice-based training and ongoing professional development. Furthermore, educational institutions must support digital infrastructure and learning ecosystems that encourage innovation and creativity in the use of technology. Tovmasyan & Ghazeyan (2025) stated that institutional support and responsive instructional design strongly influence students' experiences in digital learning. In the long term, technologies such as AR, simulations, and virtual laboratories will enrich the physics learning experience and shape a generation that thinks critically, adapts to technology, and can connect scientific concepts to the real world. Therefore, holistic and sustainable educational transformation should incorporate the use of contextual technology.

3.3. Teachers' competence in implementing technology-based physics learning

The effectiveness of implementing technology-based contextual physics education is the result of a complex interaction of various interrelated factors, ranging from teacher readiness and institutional support to access to devices and connectivity. Contextual technologies such as digital simulations, virtual laboratories, and augmented reality will only deliver optimal results if integrated into a supportive educational system. Curriculum policies, training, and the readiness of educational institutions in various countries significantly influence teachers' digital competence, according to Tomczyk (2025). Similarly, Zhang and Yu (2022) reported that teachers' perceptions of technology-based pedagogical innovations are a key determinant of the sustainability of technology practices in the classroom. Even in medical education, as explained by Çiftçi & Topçu. (2022), contextual factors such as technical support, prior experience, and perceived efficacy play crucial roles in the adoption of distance learning systems. This underscores the strategic role of individual and institutional readiness in ensuring the successful integration of contextual technology into learning, including experimental and conceptual physics.

Teacher readiness in digital literacy and technology pedagogy is one of the key prerequisites for the success of technology-based contextual physics learning. Max et al. (2023) emphasized that exploratory experiences in makerspaces can help preservice teachers develop TPACK knowledge, which is essential for designing technology-based learning. Similarly, Ma et al. (2024) demonstrated that a design-led learning approach fosters online collaboration and strengthens teachers' digital pedagogical literacy, including in language learning contexts, whose pedagogical principles can be adapted to physics teaching. Sridharan and Sequeira (2024) further emphasized the need for teachers to be prepared to understand the application of artificial intelligence (AI) to support assessment and learning in the classroom. In the context of primary education, López et al. (2023) explain how teacher training in the use of gamification significantly impacts the successful integration of technology into formal learning. Therefore, applied and contextual professional training is an important foundation for fostering teacher confidence in effectively implementing contextual technology in physics teaching.

In addition to individual readiness, the successful implementation of contextual technology also depends on institutional support encompassing structural, technical, and organizational cultural aspects. Krsmanovic et al. (2024) highlighted the importance of organizational resilience and collaborative leadership during crises such as the COVID-19 pandemic, enabling the continued adoption of learning technologies even in emergencies. In an interuniversity context, Piña-Stranger et al. (2023)

revealed that managing digital collaboration requires synergy between institutional policies, infrastructure readiness, and flexible pedagogical design. Fu et al. (2024) demonstrated that the success of digital simulation-based education is determined not only by the availability of devices but also by a systemic evaluation system and administrative support. Moreover, Nie & Wang (2024) developed a system for evaluating teaching quality based on the AHP and Delphi methods to support data-driven decision-making, an approach particularly relevant for institutions seeking to monitor the effectiveness of technology integration in subjects such as physics. These findings collectively emphasize that educational institutions need to provide adaptive structures and support systems that encourage teacher innovation, rather than simple hardware.

Access to devices, digital infrastructure, and technical support are key elements in determining the effectiveness of contextual technology implementation. Technology alone will not democratize education, as social and economic disparities and noninclusive device design remain major barriers to equitable access (Bulathwela et al., 2024). Panakaje et al. (2024) emphasize that technology integration must be accompanied by an inclusive approach and gradual improvement in teacher performance, especially in institutions still facing resource constraints. In the context of higher education, Poo et al. (2023) identified various access challenges in training, such as limited infrastructure and equipment distribution, which parallel the obstacles faced by schools seeking to implement virtual physics laboratories. Horváth & Berki (2022) emphasized the importance of designing technology systems that consider the cognitive load and workflow of users so that technology adoption does not become mentally burdensome for teachers and students. Therefore, in the context of physics education, disparities in access and nonuser-friendly technology design pose real challenges that must be addressed to ensure truly effective and equitable implementation.

The effectiveness of contextual technology integration in physics education requires a systemic approach that combines personal readiness, institutional support, and technology design that is responsive to local contexts. In another study, Ma et al. (2024) emphasized that exploring digital literacy in various countries shows that success depends on understanding local culture, regulations, and educational dynamics. Moreover, Chernikova et al., (2020), through a systematic review of modeling in educational simulations, reported that the user experience, authenticity of the learning environment, and depth of emotional engagement significantly affect the effectiveness of simulation-based learning. We can apply these findings to AR/VR-based contextual physics learning, where visual design and interactive experiences strongly influence students' learning experiences. Therefore, the implementation of technology in physics education cannot be standardized but must be tailored to the local characteristics, resource readiness, and pedagogical orientation of each institution. A cross-disciplinary and collaborative approach among teachers, technology designers, and policymakers will be key to building sustainable, equitable, and impactful integration. A summary of the main research findings related to research question 3 (Q3) is presented in Table 7 below.

3.4. Geographical gaps and the sociocultural context in technology implementation

Several studies have explicitly addressed the issues of local wisdom, urban–rural disparities, and sociocultural barriers in science education. These studies offer important perspectives on how physics education cannot be separated from the social, cultural, and geographic contexts in which students live. This analysis is crucial because it demonstrates that the effectiveness of technology integration into physics education depends heavily on local contextual suitability, community cultural engagement, and awareness of accessibility challenges faced by schools in areas with limited infrastructure. Thus, this analysis enriches the pedagogical dimension and emphasizes the importance of an inclusive and locally based approach to physics learning innovation.

Geographic factors and sociocultural conditions significantly influence the implementation of contextual technology in education. However, a major barrier to the adoption of inclusive educational technology remains the digital infrastructure gap between urban and rural areas. Limited internet access and a lack of resources in rural schools directly hinder technology implementation (Chang & Kidman, 2023). Furthermore, Giannini and Bowen (2022) reported that, within a gender and cultural context, female students from rural communities experience limited digital access under certain conditions, suggesting that the gap is not only geographical but also social.

This situation confirms that sociocultural resistance plays a role in shaping attitudes toward technological innovation. Jogezai et al. (2021) reported that teachers in remote areas experience professional isolation and limited collaboration in using social media for online learning. The lack of training tailored to local needs exacerbates this situation. Conversely, Liarokapis et al. (2024) showed that active teacher involvement in the XR technology design process can increase the technology's relevance and adaptability to local realities. Institutional readiness and social support are crucial in creating personalized and meaningful learning processes through technology (Komalawardhana and Panjaburee, 2024).

Awareness of the importance of localizing educational technology also encourages the emergence of a value-based approach. This approach is not only adaptive but also transformative. Examples of innovations that have been implemented in cultural elements include the integration of ethnoscience and the "Ancak Robyong" tradition into physics learning materials (Saminan et al., 2024; Nadzirin et al., 2024). This effort strengthens the connection between scientific concepts and students' local identities. Utami et al. (2024) support this finding by emphasizing that local culture-based research is crucial for bridging gaps in technology implementation. Furthermore, Nisa' and Suprapto (2024) noted that factors such as residence and gender bias can influence the results of ethnoscience-based learning assessments.

Table 7 Main findings of research question 3 (Q3).

Factors	Subfactors	Researchers	Important Information
Teacher Readiness	- Digital literacy - TPACK competency - Perception of innovation - Technology learning design skills	Max et al. (2023), Sridharan & Sequeira (2024), Ma et al. (2024)	Applied training encourages teachers' confidence in adopting technology.
Institutional Support	- Infrastructure - Organizational leadership - Adaptive policies - Collaboration between units	Krsmanovic et al. (2024), Fu et al. (2024), Piña-Stranger et al. (2023)	Systemic support, not just the provision of tools
Access to Technology	- Hardware & software - internet - Inclusive system design - Availability of technical assistance	Bulathwela et al. (2024), Poo et al., (2023), Panakaje et al. (2024)	Inequality of access remains a major obstacle to effective learning.
Contextual Pedagogical Approach	- Authentic simulation - Gamification - AI in assessment - Experience-based learning	López et al. (2023), Chernikova et al., (2020), Zhang & Yu (2022)	Effectiveness increases when the approach is tailored to the local context and student needs.
Cross-Disciplinary Systemic Factors	- Organizational culture - National policy support - Collaboration between technology designers and teachers	Tomczyk (2025), Ma et al. (2024), Nie & Wang (2024)	Cross-actor collaboration is necessary for sustainable and equitable integration.

Source: Scopus database.

Furthermore, contextual technology approaches have begun to be implemented in the form of culture-based teaching materials that utilize local wisdom. Some examples include the Karapan Sapi tradition as a vehicle for physics learning (Deta et al., 2024a; 2024b), the traditional game of engklek (traditional hopscotch) in practical experiments (Rizki et al., 2023), culture-based mobile learning (Susanto et al., 2023), and mapping the direction of learning development on the basis of local wisdom (Muhammad et al., 2022). This study demonstrates that a cultural approach is not merely ornamental but rather a foundation for increasing the acceptability of learning media (Mudjid et al., 2022).

The implications of such media development demonstrate the urgency of contextually relevant teacher training. Kurniawan (2021) demonstrated that the use of ethnoscience-based media can strengthen the critical thinking skills of teachers and students. Khery et al. (2021) also utilized the potential of local tourism as a natural laboratory for science education, whereas Susanto et al. (2021) developed portable laboratories to address infrastructure limitations in frontier, disadvantaged, and outermost regions. Other pedagogical strategies, such as flipped learning (Zain et al., 2022) and the development of physics comics based on traditional games (Sari et al., 2020), further strengthen teachers' capacity to deliver material contextually and engagingly.

An extension of this idea involves applying a culture-based approach in the development of modules and other teaching tools. These include the use of local phenomena such as bamboo cannons and Kalimantan culture in the learning process (Setiyadi and Kurniawan, 2020; Ramadhan et al., 2019; Andrini et al., 2019), adaptations to the South Sulawesi context (Naqiyah and Rosana, 2019), culturally integrated PBL adaptations to strengthen students' critical thinking skills (Fauzana, 2019), and the application of locally based teachers' books as practical and contextual learning guides (Sari, 2019).

Innovation in local technology development is constantly evolving. Some of these methods integrate smartphone sensors into culture-based models (Pramuda et al., 2019), explore demographic data as a source of local identity in learning design (Suprapto, 2019), culture-based digital media to support teachers' perceptions and readiness for local content (Delima, 2018; Putry, 2018; Martawijaya, 2018; Hartini et al., 2018), "saraba ka-wa"-based teaching materials to reinforce character values, and traditional architectural ecosystems as relevant and contextual physics learning media (Napitupulu et al., 2018; Nasrudin et al., 2018).

The application of local values in the digital realm has also experienced significant development. Husna and Kuswanto (2018) successfully improved the understanding of vector concepts through culture-based mobile learning, whereas Hartini et al. (2017) demonstrated the effectiveness of culture-based teaching materials in shaping student character. The integration of local values into digital content not only increases student engagement but also strengthens the identity dimension and the meaningfulness of learning.

These findings demonstrate that geographic disparities and sociocultural barriers not only hinder access to technology but also reduce the relevance and acceptance of learning innovations. Therefore, the integration of contextual technology into education must be designed in a participatory manner, taking into account mapping local values, strengthening teacher capacity, and designing strategies that are responsive to the geographic and cultural conditions of the community.

4. Future Research Potentials

This study provides directions for future research focused on developing an artificial intelligence (AI)-based adaptive physics learning model capable of adjusting content, context, and difficulty levels on the basis of student learning profiles. Machine learning can enhance teachers' diagnostic capabilities and reveal patterns of student engagement in AR/VR-based environments. Furthermore, longitudinal research is needed to evaluate the long-term effects of contextual technology integration on critical thinking skills, creativity, and scientific literacy. Such studies can also reveal the dynamics of the relationships among teacher readiness, institutional support, and digital infrastructure across different regions (urban and rural).

In a cultural context, future research is expected to explore the integration of ethnophysics and local wisdom-based digital pedagogy to create learning models that are not only cognitively effective but also strengthen students' local identities. A participatory design methodology that includes educators and local communities can yield innovations that are more pertinent and enduring. Policy research is also needed to assess the readiness of educational institutions to implement technology-based contextual learning. Comparative studies across developing countries can reveal the best policy adaptation models for inclusive and evidence-based science education systems.

5. Conclusions

A systematic review of articles published over the past decade concludes that the integration of digital technology in physics education has shown an increasing trend, with a strong tendency toward the use of augmented reality-based media, digital simulations, and other interactive platforms as part of pedagogical innovation (Q1). Contextual technologies such as virtual laboratories, simulations, and AR have been shown to increase student engagement, strengthen the understanding of abstract concepts, and expand the scope of scientific exploration without physical limitations (Q2). The effectiveness of implementing contextual technology-based learning is still influenced by various factors, such as teachers' pedagogical readiness, support from educational institutions, and gaps in access to adequate digital infrastructure (Q3). Geographical and cultural contexts play crucial roles in the successful adaptation of local wisdom-based physics learning, which not only enriches learning content but also increases the relevance and meaningfulness of learning for students in certain regions (Q4). These findings provide a strong basis for further research and the formulation of educational policies that are more responsive to technological challenges and diverse local contexts.

Although this systematic review offers an in-depth examination of trends, patterns, and research gaps related to contextual technology-based physics learning for the period 2014–2024, it still has several limitations. The review was limited to open-access articles indexed in Scopus and Springer, potentially overlooking relevant research from other databases or non-English language publications. The relatively small number of chosen articles also makes it harder to apply the results to other situations. Furthermore, most of the analyzed studies were short-term and did not evaluate the sustained impact of contextual technology-based learning on higher-order thinking skills and student learning identity formation. Therefore, future research should develop longitudinal, cross-cultural studies and explore the integration of adaptive technologies, such as artificial intelligence and participatory learning design, to make technology-based physics learning more contextual, inclusive, and sustainable.

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6. Declarations

6.1. Ethical considerations

Not applicable.

6.2. Use of artificial intelligence (AI)

The authors declare that the generative artificial intelligence (AI) tool [Grammarly] was used exclusively for language editing and/or grammatical improvement. The use of AI did not influence the scientific content, study design, data analysis, data interpretation, results, or conclusions of the manuscript. Full responsibility for the content remains with the authors.

6.3. Conflict of interest

The authors declare that they have no conflicts of interest.

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