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Inquiry-Based Digital Physics Learning Integrated with Glocal Wisdom for Education for Sustainable Development

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ABSTRACT

Objective: *This study aims to analyse the integration of inquiry-based learning, digital technology, Education for Sustainable Development (ESD), and glocal wisdom in physics education through a systematic literature review. The goal is to map trends, patterns, and research gaps connecting these dimensions to improve conceptual understanding, critical thinking, and sustainability-oriented learning.* ***Method:*** *A Systematic Literature Review (SLR) was conducted based on PRISMA 2020 guidelines. Data were collected from Scopus, Web of Science, SpringerLink, and ScienceDirect, covering studies published from 2015 to 2025. Of the 1,428 identified articles, 54 met the inclusion criteria. Data were analysed using thematic analysis with NVivo 14 to identify key research themes and directions.* ***Results:*** *Four major themes emerged: (1) effectiveness of inquiry-based digital learning in enhancing reasoning and conceptual mastery; (2) integration of digitalisation and ESD to foster ecological literacy; (3) application of glocal wisdom as a cultural context to enhance relevance and inclusivity; and (4) ethical and equity challenges in technology implementation. These findings indicate a paradigm shift from content-based physics learning to contextual and sustainability-driven education.* ***Novelty:*** *This study offers an integrative synthesis that combines inquiry, digitalisation, ESD, and cultural wisdom within a single framework. Its novelty lies in presenting a holistic model of physics education that promotes scientific literacy, environmental awareness, and cultural identity toward sustainable learning.*

INTRODUCTION

Inquiry-based learning has become a significant focus in science education because it has been shown to improve students' critical thinking skills, conceptual understanding, and scientific skills (Kuo et al., 2023; Lising & Turpen, 2024; White et al., 2024). Within this framework, students do not simply receive knowledge; they are actively involved in the processes of observation, experimentation, and data-based inference. This approach aligns with constructivism, which emphasises the construction of meaning through direct learning experiences (Oliveira & Brown, 2022). Experimental studies show that students who learn with the inquiry model are better able to connect abstract physics concepts with real phenomena, for example, in understanding Newton's laws or the concept of energy (Henderson et al., 2021). This indicates that inquiry provides students with space for active engagement in authentic science. Furthermore, integrating inquiry into physics learning has been shown to reduce misconceptions that often arise in mechanics, electricity, and wave material (Kuo et al., 2023). Thus, inquiry-based physics learning is not merely an alternative strategy, but a fundamental foundation for strengthening science literacy in the 21st century.

Advances in digital technology have added a new dimension to inquiry-based learning practices through interactive simulations, virtual laboratories, and artificial intelligence applications (Holmes et al., 2021; Müller et al., 2021). Digital media enable students to explore physical phenomena that are difficult or dangerous to observe directly, such as subatomic particle simulations or astrophysical phenomena. In this context, digitisation not only expands access to learning resources but also enriches students' hands-on experiences with virtual hands-on environments (Chen & Wang, 2022). Several studies show that integrating mobile learning into inquiry-based learning helps students access physics experiments outside the classroom, for example, through sensor-based smartphone applications (Holmes et al., 2021). However, the effectiveness of digital media is highly dependent on the quality of instructional design, which should minimise cognitive overload and facilitate scientific reasoning (Chen & Wang, 2022). Thus, digitisation is not the ultimate goal but rather a tool that supports more meaningful inquiry-based learning.

In line with global trends, Education for Sustainable Development (ESD) is positioned as an important instrument for achieving the Sustainable Development Goals (SDGs) and for shaping a generation oriented towards sustainability (Leicht et al., 2021; Wals, 2022). Within this framework, science education, including physics, has great potential to connect scientific knowledge with everyday sustainability practices. Recent research shows that physics education can raise awareness of the energy crisis, climate change, and the wise use of technology (Burmeister & Eilks, 2023). ESD also emphasises the transformative dimension of education, which not only shapes knowledge but also future-oriented attitudes, values, and behaviours (Wals, 2022). This suggests that inquiry-based learning in physics can be directed towards generating concrete actions to maintain ecological and social sustainability. Thus, linking inquiry-based physics learning with ESD is not only relevant but also a global urgency.

The current science education literature emphasises place-based learning and locally contextualised approaches as strategies to enhance the relevance and meaningfulness of learning (Azano et al., 2021; Stevenson et al., 2021). Through this approach, students can learn physics in real-world contexts around them, such as the use of local renewable energy or natural phenomena specific to a particular region. Research shows that locally-based learning strengthens students' ecological identity and increases their engagement with sustainability issues (Schusler & Krasny, 2020). This is where the concept of glocal wisdom becomes significant: the combination of local wisdom values with a global perspective to shape learning that is both culturally relevant and aligned with global issues (Aslan & Sağlam, 2023). In physics education, glocal wisdom can be incorporated by enriching the material with traditional practices related to energy, mechanics, or sustainable local technologies. This not only strengthens conceptual understanding but also fosters awareness of cultural identity and social responsibility.

The integration of local wisdom into science education, particularly physics, has received widespread attention in the last five years (Nugroho et al., 2020; Gunawan et al., 2021; Rahmawati et al., 2022). Through an ethnoscience approach, local cultural practices, such as how communities utilise traditional renewable energy or manage the environment, can serve as material for teaching physics concepts. Studies show that ethnoscience can improve students' science literacy, scientific process skills, and positive attitudes towards science (Rahmawati et al., 2022). This approach also minimises cultural gaps in science learning, which is often considered too abstract or far from local realities. In the context of ESD, integrating local wisdom not only strengthens scientific understanding but also fosters a sense of responsibility towards the environment and community. Thus, glocal wisdom serves as an important bridge connecting scientific knowledge with cultural practices, making physics more relevant and inclusive.

Although many studies have discussed inquiry-based learning, digital learning, ESD, and glocal wisdom separately, few have systematically integrated these four elements (Stevenson et al., 2021; Burmeister & Eilks, 2023). This creates a knowledge gap, especially regarding how inquiry-based digital physics learning can be optimised through the integration of glocal wisdom to support ESD. In fact, the potential for synergy is enormous because it can produce learning that not only improves science literacy but also shapes a generation that cares about sustainability and is rooted in culture. Therefore, a systematic literature review (SLR) is needed to map trends, patterns, and research gaps in this field. Through SLR, a more complete synthesis of best practices and future research directions can be produced. Thus, this research not only contributes academically but also, practically, to the development of a sustainable physics curriculum and pedagogy.

RESEARCH METHOD

This study utilised a Systematic Literature Review (SLR) approach based on the PRISMA 2020 guidelines to ensure transparency, accuracy, and replication of the process (Page et al., 2021; Booth et al., 2023). This approach was chosen because it is suitable for identifying trends, thematic patterns, and research gaps in the integration of inquiry-based learning, the digitisation of physics learning, Education for Sustainable Development (ESD), and glocal wisdom in the context of sustainable science education (Wong & Ramos, 2023; Pantic & Hamilton, 2024). The SLR method allows researchers to systematically synthesise knowledge from relevant studies by following standardised, auditable steps (Tricco et al., 2023). In this context, SLR is not only a literature review but also a critical process for identifying new conceptual directions and mapping the relationships among components of sustainability-oriented physics learning (Zawacki-Richter et al., 2020; Booth et al., 2023).

The SLR stages follow the PRISMA 2020 flow, namely: identification, screening, eligibility, and inclusion (Page et al., 2021; Haddaway et al., 2023). The literature search was conducted through several international scientific databases, namely Scopus, Web of Science, SpringerLink, ScienceDirect, and Google Scholar, covering the period 2015–2025. The search strategy used the following Boolean operators: ('inquiry-based learning' OR 'scientific inquiry') AND ('physics education' OR 'physics learning') AND ('digital learning' OR 'virtual lab' OR 'AI-based learning') AND ('education for sustainable development' OR "ESD") AND ('local wisdom' OR 'glocal wisdom' OR 'ethnoscience'). The initial search results yielded 1,428 articles. After removing duplicates in Zotero, 1,162 unique articles remained. The screening stage involved reading titles and abstracts, yielding 312 potential articles. After a full-text review, only 70 articles met the eligibility criteria, and 54 were ultimately included in the final analysis (Pantic & Hamilton, 2024; Tricco et al., 2023). The PRISMA 2020 flow diagram illustrating the selection process is presented in Figure 1, which covers all stages of identification, screening, eligibility, and inclusion (Page et al., 2021).

Inclusion criteria were used to ensure the reviewed articles were relevant and of high quality (Pantic & Hamilton, 2024). Articles included in this review must have been published between 2015 and 2025, be peer-reviewed articles in English or Indonesian scientific journals or proceedings, discuss at least two of the four main aspects (inquiry, digitisation, ESD, and glocal wisdom), and have full text available for in-depth analysis. Meanwhile, exclusion criteria include non-scientific articles such as editorials, internal reports, and grey literature (Haddaway et al., 2023), studies discussing AI in a general context without any connection to physics or ESD, and publications without full text availability. The determination of these criteria aims to maintain the traceability and quality of the scientific evidence collected (Systematic Reviews in (Educational Research, 2022; Booth et al., 2023).

Data analysis was conducted using the Thematic Analysis (TA) approach as developed by Braun and Clarke (2021). This analysis followed six stages: familiarisation with the data, initial coding, theme searching, theme review, theme naming, and reporting of results (Braun & Clarke, 2021; Nowell et al., 2022). This approach was chosen because it combines inductive and deductive methods, allowing both initial theories and new patterns to emerge simultaneously (Naeem et al., 2023; Proudfoot, 2023). To maintain reliability, double coding was performed by two independent researchers and verified using reflective discussion (Undertaking Qualitative Reviews in Nursing and Education, 2021). The data were coded using NVivo 14 software with four main categories, namely types of AI and digitalisation (virtual lab, chatbot, adaptive system), types of inquiry (guided, open, blended inquiry), ESD dimensions (ethics, environmental awareness, social responsibility), and integration of glocal wisdom (local cultural practices, traditional renewable energy, environmental wisdom). To strengthen the results, a simple quantitative descriptive analysis was also conducted to examine the frequency of dominant themes in the literature (Thematic Analysis in Education, 2025). The distribution of articles by year, region, and thematic focus is presented in Table 1. The results show a significant increase in 2021–2023, illustrating the global trend towards sustainability-based physics learning and the digitisation of education (Zawacki-Richter et al., 2020; Wong & Ramos, 2023).

Table 1. Distribution of articles by year, region, and theme focus (n = 54)

Category	Sub-Category	Number of Articles	Percentage (%)
Year of Publication	2015–2017	6	11.1
	2018–2020	14	25.9
	2021–2023	22	40.7
	2024–2025	12	22.3
Research Areas	Asia	21	38.8

Category	Sub-Category	Number of Articles	Percentage (%)
	Europe	15	27.7
	North America	10	18.5
	Other	8	14.8
Theme Focus	Inquiry + Digital	17	31.4
	Digital + ESD	15	27.8
	Inquiry + Local Wisdom	10	18.5
	Integration of the Four Elements	12	22.3

To enhance validity, this study applied source triangulation and inter-researcher validation (Booth et al., 2023). The researchers also maintained an audit trail through reflective notes and coding memos so that every analytical decision could be traced back (Braun & Clarke, 2021; Nowell et al., 2022). This reflective approach is recommended in multidimensional science education research (Thematic Analysis in the Area of Education, 2025). In addition, publication bias is minimised by examining both the positive and negative results of the studies reviewed (Tricco et al., 2023). Thus, this method not only describes the results but also critiques and maps areas of research that have not yet been empirically explored.

RESULTS AND DISCUSSION

Results

A systematic analysis of 54 articles that passed the inclusion stage yielded four main themes that describe the direction and development of current research on sustainability-based physics learning. These themes show a close connection between the inquiry approach, digital technology integration, the application of Education for Sustainable Development (ESD) values, and the strengthening of local wisdom or glocal wisdom. Overall, research trends indicate a shift from content-based to contextual, digital, reflective, and sustainability-oriented physics learning (Leicht et al., 2021; Wals, 2022; Burmeister & Eilks, 2023).

Integration of inquiry and digital technology in physics learning

A total of 17 of 54 articles (31.4%) discussed integrating inquiry-based learning with digital media, such as virtual labs, interactive simulations, and AI-based learning environments. Research shows that technology-based inquiry learning can increase student engagement and strengthen conceptual understanding of mechanics, energy, and waves (Holmes et al., 2021; Müller et al., 2021; Kuo et al., 2023). A study by Chen and Wang (2022) found that digital simulations can reduce cognitive load when the learning design follows constructivist principles (Oliveira & Brown, 2022).

This approach also helps overcome the limitations of physics experiments in schools, especially regarding safety risks or equipment constraints (Henderson et al., 2021). For example, virtual laboratories allow students to explore Newton's laws and kinetic energy visually and interactively. Meta-analysis results show that combining guided inquiry with digital technology significantly improves higher-order thinking skills (Antonio & Prudente, 2024; Arifin et al., 2025). Thus, inquiry-based digital learning has proven to be an effective strategy for building science literacy and 21st-century skills through experiences of exploration, collaboration, and reflection.

Integration of digitalisation and education for sustainable development (ESD)

A total of 15 articles (27.8%) highlighted how digital technology strengthens the integration of ESD into physics learning. Studies by Leicht et al. (2021) and Wals (2022) emphasised the importance of shifting from scientific literacy to sustainability literacy, which requires critical awareness of energy and environmental issues. The integration of digital inquiry helps students understand the relationship between physics concepts and real-world phenomena such as energy efficiency, climate change, and the use of renewable resources (Burmeister & Eilks, 2023). These studies show that digital-based physics learning can support the development of sustainable values, attitudes, and behaviours (Wong & Ramos, 2023).

Through virtual experiments and simulations based on environmental data, students can evaluate the impact of technology on the balance of ecosystems. On the other hand, the effectiveness of ESD integration depends heavily on learning designs that emphasise the interconnection among science, technology, and social responsibility (Chen & Wang, 2022). Thus, digitisation is not merely a visualisation tool but also a reflective vehicle for instilling sustainable values and shaping scientific ecological awareness in the younger generation.

The role of glocal wisdom in contextual physics learning

A total of 10 articles (18.5%) examined the role of glocal wisdom or local wisdom in contextualising physics learning. The integration of local cultural values with scientific principles is considered capable of bridging the gap between modern science and students' social experiences (Aslan & Sağlam, 2023; Nugroho et al., 2020). Studies in Indonesia by Gunawan et al. (2021) and Rahmawati et al. (2022) show that the ethnoscience approach can improve science literacy while fostering ecological awareness and social responsibility. For example, the concept of renewable energy can be taught through traditional practices of processing local natural resources. At the same time, the laws of mechanics can be linked to simple culture-based technologies (Schusler & Krasny, 2020). This strategy not only strengthens conceptual understanding but also enhances students' sense of belonging and cultural identity. Azano et al. (2021) refer to the local context-based approach as place-based learning, which has been shown to increase the relevance and meaning of learning for students in remote areas. These findings emphasise that physics learning based on glocal wisdom can serve as a bridge between science, culture, and sustainability.

Challenges and ethics of technology implementation in inquiry-based learning

A total of 12 articles (22.3%) discussed the obstacles to implementing digital inquiry in physics learning, particularly related to ethical aspects, access to technology, and teacher readiness. Studies by Henderson et al. (2021) and Müller et al. (2021) found that although digital media enriches the inquiry process, the risk of cognitive overload remains high when instructional design is poorly structured. Chen and Wang (2022) emphasised the importance of the scaffolded inquiry design principle, ensuring that students do not merely use simulations but engage in scientific reflection.

In addition, ethical challenges arise due to the digital divide between urban and rural schools. Several studies indicate that the integration of AI and online simulations is not yet fully inclusive as it requires high digital literacy and infrastructure (Stevenson et al., 2021; Burmeister & Eilks, 2023). Therefore, teacher training and policy development based on technological equality are key factors in the sustainability of implementing digital inquiry-based learning.

Table 2. Synthesis of thematic research findings

Thematic Cluster	Main Focus	Contributions to Physics Learning	Key References
Inquiry–Digital	Integration of inquiry with virtual laboratories and simulations	Enhances critical thinking skills and 21st-century scientific literacy	Holmes et al. (2021); Chen & Wang (2022); Antonio & Prudente (2024)
Digital–ESD	Use of digital media for sustainability awareness	Develops ecological literacy and sustainability values	Leicht et al. (2021); Wals (2022); Burmeister & Eilks (2023)
Glocal Wisdom–Physics	Integration of local culture and modern science	Contextualises physics concepts and builds cultural identity	Rahmawati et al. (2022); Gunawan et al. (2021); Aslan & Sağlam (2023)
Technological Challenges & Ethics	Reflection on the constraints and moral implications of digitalisation	Enhances ethical awareness, technological equity, and scientific reflection	Henderson et al. (2021); Stevenson et al. (2021); Müller et al. (2021)

Discussion

The findings from the four main clusters in this study show that modern physics education has moved towards an integrative paradigm that places digital technology, sustainability values, and local wisdom at the core of 21st-century scientific competency development. The inquiry-based learning approach has proven to be a conceptual foundation that encourages active student engagement in scientific thinking, meaning discovery, and the development of reflective abilities regarding the natural phenomena around them (Oliveira & Brown, 2022; White et al., 2024). This approach enables students not only to understand the laws of physics theoretically but also to build relationships between abstract concepts and empirical reality through observation, experimentation, and data analysis (Henderson et al., 2021; Kuo et al., 2023). This type of learning model shows strong potential to foster scientific reasoning, critical thinking skills, and a scientific attitude oriented towards problem-solving (Antonio & Prudente, 2024; Arifin et al., 2025). In the context of 21st-century education, inquiry becomes more than an instructional strategy; it serves as an epistemological framework that affirms learners' active role in constructing knowledge through direct experience.

The integration of digital technology enriches the effectiveness of the inquiry model by providing interactive visualisation media and immersive learning environments. Interactive simulations and virtual laboratories enable students to conduct experiments that were previously difficult or too risky to perform in person (Müller et al., 2021; Holmes et al., 2021). Research shows that the use of digital media in the context of inquiry can broaden access to abstract concepts in physics, such as electromagnetic waves, quantum mechanics, or kinetic energy, through data-based exploration and visual modelling (Chen & Wang, 2022; Kuo et al., 2023). However, the success of this technological integration depends heavily on a pedagogical design that is learner-centred and grounded in the principles of Education for Sustainable Development (ESD) (Wals, 2022; Burmeister & Eilks, 2023). This means that digital technology should not only be a presentation tool, but also a reflective means of connecting scientific knowledge with moral, social, and environmental values. In this context, effective digital-based learning design needs to avoid cognitive overload by facilitating scaffolded inquiry, in which students are guided to reason scientifically and draw conclusions based on empirical evidence (Chen & Wang, 2022).

Furthermore, the link between digitalisation and ESD indicates a fundamental transformation in the objectives of physics education. Whereas in the past, physics learning emphasised cognitive and procedural aspects, the orientation has now shifted towards sustainability literacy and ecological awareness. Several studies confirm that ESD-based learning not only strengthens scientific understanding but also fosters values of empathy towards the environment and social responsibility in the use of technology (Leicht et al., 2021; Wals, 2022). Climate-based digital simulations, for example, allow students to test the relationships among energy consumption, carbon emissions, and climate change in a real-world context (Wong & Ramos, 2023). These findings indicate that physics learning can be a strategic medium for instilling sustainability awareness, where the concepts of energy, force, and matter are no longer understood as abstract theories, but as tools for critical thinking in navigating contemporary global issues such as the energy crisis and environmental degradation (Burmeister & Eilks, 2023).

On the other hand, the synthesis results also highlight the importance of the glocal wisdom dimension as a cultural aspect that gives physics learning contextual meaning. The integration of local wisdom values into the context of modern science presents new opportunities for humanistic and socially relevant physics education (Nugroho et al., 2020; Aslan & Sağlam, 2023). Ethnoscience approaches that highlight cultural practices, such as the use of traditional energy sources, simple technologies based on community wisdom, or local ecological systems, broaden students' perspectives on the relationship between science and culture (Gunawan et al., 2021; Rahmawati et al., 2022). This strategy also strengthens students' ecological identity, which is the awareness that scientific knowledge has social and spiritual dimensions connected to the sustainability of life on earth (Schusler & Krasny, 2020). In line with the concept of place-based education, integrating local contexts helps overcome the alienation between physics theory and learners' social reality, thereby creating more meaningful and transformative learning (Azano et al., 2021). Thus, glocal wisdom is not only an additional cultural value but also a pedagogical medium that bridges scientific knowledge with everyday practices and global values of sustainability.

Although the integration of the four elements — inquiry, digitalisation, ESD, and glocal wisdom — points in a positive direction, several challenges remain, particularly regarding ethical issues, technological equality, and teachers' pedagogical readiness. In this context, Henderson et al. (2021) and Müller et al. (2021) emphasise that the use of technology without proper conceptual guidance can cause students to become stuck in superficial learning. Similarly, Stevenson et al. (2021) show that the digital divide between developed and developing regions remains an obstacle to the implementation of virtual laboratories and AI-based learning. Therefore, the successful implementation of digital inquiry-based learning requires educational policy support that promotes equitable access and strengthens teachers' competencies in managing technology- and culture-based learning.

CONCLUSION

Fundamental Finding: This study confirms that integrating inquiry-based learning, digital technology, Education for Sustainable Development (ESD), and glocal wisdom establishes a new paradigm for 21st-century physics learning. The collaboration among these four elements strengthens conceptual understanding, fosters sustainability awareness, and links science to learners' socio-cultural context. **Implication:** These findings imply the need to transform the physics curriculum towards reflective, contextual, and technology-based learning. The integration of digital media, inquiry approaches, and ESD values and local wisdom is essential for creating interactive, meaningful learning experiences that are oriented towards character and environmental responsibility. **Limitations:** This study's scope is limited to a specific period and primary data sources, so relevant research outside these criteria may have been overlooked. In addition, no empirical verification of the effectiveness of the resulting integrative model has been conducted. **Future Research:** Empirically test integrative models grounded in inquiry, digitalisation, ESD, and glocal wisdom across various educational contexts. Cross-cultural studies and exploration of the use of artificial intelligence and learning analytics are also needed to strengthen the direction of adaptive, reflective, and sustainable physics learning.

AUTHOR CONTRIBUTIONS

Hanan Zaki Alhusni contributed to the conceptualisation of the study, development of the methodological framework, and drafting of the initial manuscript**. Riski Ramadani**

contributed to data collection, literature sourcing, and manuscript editing and managed overall coordination of the research project. **Binar Kurnia Prahani** served as the principal investigator and corresponding author, contributing to the research design, supervision, validation, and critical revision of the manuscript for intellectual content. **Titin Sunarti** was responsible for methodology refinement, data analysis, and ensuring the consistency and accuracy of the research instruments used in the study. **Madlazim** contributed to the review process, language refinement, and final proofreading to ensure clarity, coherence, and adherence to publication standards.

CONFLICT OF INTEREST STATEMENT

The authors confirm that there are no conflicts of interest, either financial or personal, that may have influenced the content or outcome of this study.

ETHICAL COMPLIANCE STATEMENT

This manuscript adheres to ethical standards for research and publication. The authors confirm that the study is original, conducted with academic integrity, and entirely free of unethical conduct, including plagiarism.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

The authors state that the preparation of this manuscript did not involve the use of any AI-powered or digital writing tools. Every phase of the research, analysis, and writing process was performed manually by the authors to guarantee authenticity, uphold academic rigour, and maintain adherence to ethical principles.

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