

School Studies Mapping Integrated Physics–Math Instructional Designs and Learning Outcomes

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ABSTRACT

This research aims to systematically examine the application of physics-mathematics integration and its impact on learning. Through the Systematic Literature Review approach, this article analyzes 15 selected empirical research articles obtained from the Scopus and ScienceDirect databases. Article selection guided by the PRISMA method. The analysis yields five instructional design orientations that integrate physics and mathematics learning, namely problem–project integration, representation–transition integration, cross-disciplinary integration, tech–creative integration, and cognitive–affective integration. The study also found that such integrative design not only improves cognitive performance but also fosters creativity, collaboration, and confidence, which are important competencies for scientific literacy and problem-solving.

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INTRODUCTION

Mathematics is often referred to as the language of physics, highlighting their deep interconnectedness. This relationship is essential for understanding and solving physics problems, as mathematical skills are required to model and analyze physical phenomena (El Azzouzi et al., 2025; Pospiech et al., 2015; Pospiech, 2023; Serpe, 2023). Integrating mathematics into physics education helps students understand complex concepts more effectively. For example, solving physics problems often requires a strong understanding of algebra and geometry, which can be challenging if taught separately (Gabková & Halusková, 2016). Real-world challenges often require a holistic approach that combines various STEM disciplines. Integrated STEM education, which includes math and physics, prepares students to address these challenges by providing a comprehensive understanding of how these fields interact (Kelley et al., 2023; Spreitzer et al., 2024).

Students who learn physics and mathematics in an integrated manner develop better problem-solving skills. This is because they can apply mathematical techniques directly to physical problems, leading to a deeper understanding and more effective solutions (Tong et al., 2025). Integrating mathematics into physics can make learning more

engaging for students. When students see the practical applications of mathematics in physics, they are more likely to develop an interest in both subjects (Azzouzi et al., [2023](#)).

Integrated physics–mathematics instruction can be applied in a variety of learning contexts. This approach includes primary model-based representation and construction (Tytler et al., [2021](#)), and secondary computational modeling through simulations developed by the students themselves (Taub et al., [2018](#)). Some studies also incorporate various forms of representation and empirical data, particularly in the topic of heat and mechanics (Amanati, [2020](#); Azizah & Setyawarno, [2025](#)). In addition, there are a number of reports in the context of STEM-PBL that focus on attitude development, although the mapping of modeling features, representations, data, and technology is still limited (Sulaiman et al., [2023](#), [2024](#); Uden et al., [2023](#)). A more in-depth theoretical framework regarding task features and mathematical aspects has also been put forward in recent research (Badmus & Jita, [2024](#); Sirnoorkar & Lavery, [2023](#)).

One of the main challenges of implementing physics-mathematics integration is the lack of teacher training in interdisciplinary teaching. Many teachers are trained in a mono-disciplinary manner, which can make it difficult for them to implement integrated teaching practices effectively (Michelsen, [2015](#); Serpe, [2025](#)). Developing a curriculum that integrates math and physics requires careful planning to ensure that the content of both subjects is covered comprehensively and coherently. This includes creating lesson plans that highlight the relationships between disciplines and using digital tools to support interdisciplinary learning (Shelekhova, [2015](#)). Therefore, a systematic literature review is needed to identify the most appropriate learning models and designs, as well as uncover the types of cognitive, conceptual, and problem-solving skills that can be improved through this integrative approach.

The systematic review proposed by the researcher is the latest inventory that has proven useful for creating interdisciplinary learning considering the existing literature tends to be fragmented based on learning design and aspects that can be improved through physics-mathematics integration. Through this study, it is hoped that a comprehensive understanding of the practice, effectiveness, and challenges of implementing physics-mathematics integration in the context of learning practices can be obtained. The results of this research are also aimed at providing conceptual and practical contributions for teachers, curriculum developers, and policymakers to develop interdisciplinary learning. Therefore, this more in-depth systematic review at a practical level is essential for physics-mathematics integration to become a directed pedagogical tool that strengthens conceptual understanding, develops problem-solving and logical thinking skills, enhances interdisciplinary relevance and interconnectedness, and supports real activity-based learning.

Based on this background, this study aims to conduct a systematic literature review of empirical studies on the application of physics-mathematics integration in the context of learning practice. Specifically, this study will answer the following two research questions:

RQ1 : How is the learning design that integrates physics-mathematics?

RQ2 : What skills can be improved through learning that integrates physics-mathematics?

METHOD

Literature Search

A systematic literature search will be conducted during June 2025 using two main databases, namely Scopus and ScienceDirect. Scopus and ScienceDirect were selected considering that the present review investigates the integration of physics and mathematics specifically within formal educational settings. These platforms provide extensive peer-reviewed coverage in education and social sciences, ensuring alignment with the study's educational focus. The search strategy used a combination of terms: physics AND mathematics AND (education OR learning) AND ("secondary school" OR "senior high school") to identify articles that discussed the application of physics-mathematics integration in learning at the secondary school level (Table 1). These terms must be listed in the title, abstract, and/or keywords section of the publication. Based on the search, a total of 367 scientific articles were found to be further analyzed at the selection stage based on inclusion and exclusion criteria (Figure 1).

Table 1. Search strings

Databases	Keywords
Scopus ScienceDirect	"physics AND mathematics AND (education OR learning) AND ("secondary school" OR "senior high school")

Study Selection Criteria

The study selection process was carried out through several stages of screening based on the inclusion and exclusion criteria that have been set. The initial 367 articles were screened based on 5 criteria, namely: (1) articles published in the period 2016 to 2025 (this timeframe was selected because research on the integration of physics and mathematics has expanded markedly since 2016, ensuring that the included studies represent contemporary conceptualizations of the field.); (2) the article is the result of empirical research (not an editorial, review, or opinion); (3) articles are included in the field of social sciences in accordance with the classification of the database; (4) the article

is written in English; and (5) the article is available in open access for full analysis. Based on the results of the screening, 45 articles were obtained that met all the requirements. A thorough reading and review was carried out on the 45 articles. Based on the content analysis, 12 main articles were selected that explicitly or implicitly discuss the integration of physics-mathematics in the context of learning in secondary schools. A further 33 articles were excluded because they did not meet thematic criteria, such as: not explicitly addressing physics-mathematics integration in the learning context; not intended for secondary school contexts; not focusing on learning design; or mentioning only part of physics-mathematics integration in learning contexts.

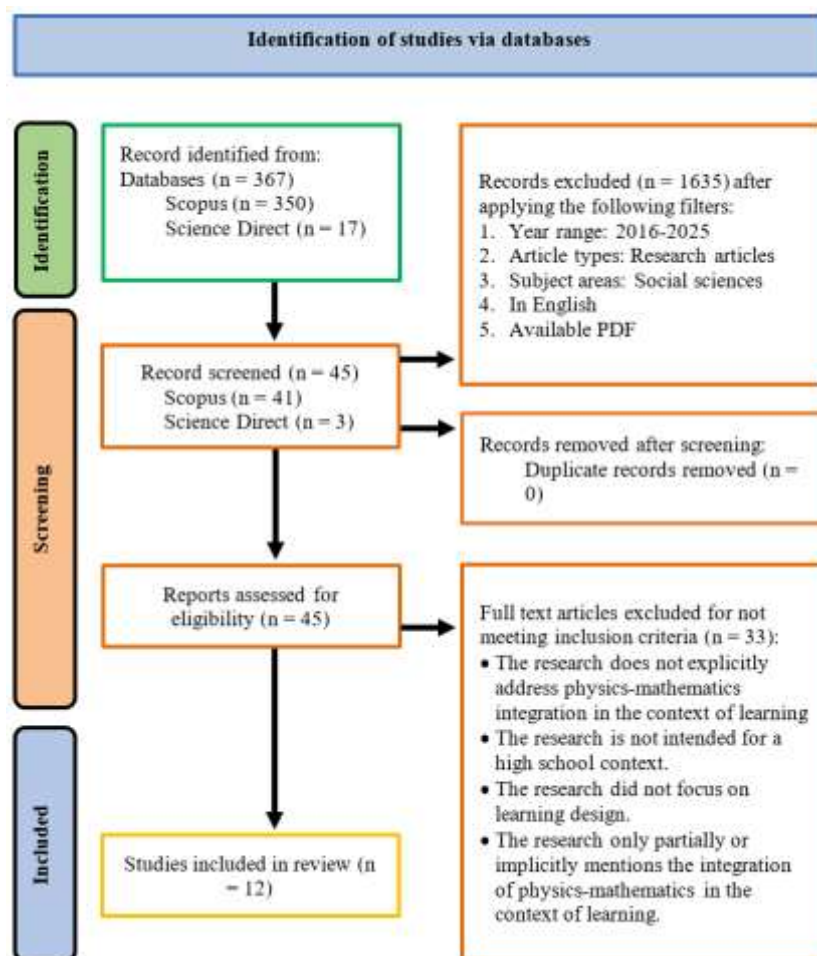


Figure 1. Primary study inclusion and exclusion process

Quality Assessment

The assessment of 12 articles was carried out by referring to the standard quality assessment criteria developed by the Kmet et al. (2004). The 5 indicators adopted from the 14 quality indicators include question/objective assessment, research design, subject characteristics, results, and conclusions. The article quality assessment process is carried

out using a three-level assessment system, where a score of 2 is given if the information or data is presented in full, a score of 1 if the information is only partially available, and a score of 0 if the information is not available at all or does not meet the set criteria. This assessment was carried out independently by the authors, and the score results of each assessor were summarized, then the percentage was calculated against the maximum total score. To determine the feasibility of an article, a threshold value of 55% is used, which is set as a relatively liberal cut-off point to remain inclusive of different types of research. Based on calculations made using Microsoft Excel, the quality value of articles that passed the selection ranged from 63.33% to 90%, with an overall average value of 79.17%, which indicates that the article has adequate methodological quality for further analysis.

Coding Study Characteristics

Studies that are considered eligible are coded based on the author's name, year of publication, research objective, research method, research sample, and country. As shown in Table 1, the selected studies were conducted between 2018 and 2025. The research sample consisted of high school students. The majority of the research was conducted in Indonesia (25%) and 8.33% respectively for Finland, Palestine, the United States, Germany, Nigeria, Sweden, Greece, Vietnam, and Italy. All studies investigated interventions to achieve significance.

Tabel 1. Characteristics of Selected Studies

Author(s), Year	Research Objectives	Research Methods	Research Sample	Country
(Parno et al., 2020)	Comparing students' scientific literacy competencies improvement through three different learning approaches: PBL-STEM, PBL pure, and conventional	Quasi-experimental with non-equivalent pretest–posttest group design	99 students	Indonesia
(Kokkonen et al., 2022)	Investigating the effectiveness of the concreteness fading and concreteness introduction approaches	Classroom experiments (between-subjects design)	70 students (about 17–18 years old)	Finland
(Mafarja et al., 2024)	Investigating the influence of cooperative learning combined with Internet Reciprocal Teaching (IRT) on students' STEM literacy attitudes and abilities	Quasi-experimental design	60 students	Palestine

(Kotsalidis et al., 2024)	Developing and evaluating a series of EMMAs (Exploring Molecular Modeling Activities) activities	Mixed methods	43 students	United States
(Lindner et al., 2019)	Developing and evaluating the new elective subject "Geography-Physics"	Formative–summative implementation and evaluation studies	24–27 students per batch (2016–2018), grades 8–9 (ages 13–15)	Germany
(Badru & Owodunni, 2021)	Investigating the influence of Mathematical Language Ability (MLA) and Parental Support (SPS)	Correlation survey design	720 students	Nigeria
(Petersson, 2024)	Exploring how students think about how computers do curve fitting	Qualitative methods based on observation of classroom activities and group interviews	20 groups in math and physics classes, with each group consisting of 2–4 students (about 16 years old)	Sweden
(Altanis et al., 2018)	Developing and evaluating innovative motion-based (touchless) game-based learning approaches using Kinect technology	Mixed methods	22 students (15 years old)	Greece
(Tang et al., 2020)	Describing cross-disciplinary collaboration between mathematics and physics teachers in designing and implementing STEM learning	Case study based on <i>lesson study theory</i>	Grade 10 students	Vietnam
(Martawijaya et al., 2023)	Knowing the influence of the application of the Ethno-STEM Project-Based Learning (PjBL) learning model	Pre-experimental design (pretest–posttest control group)	39 students	Indonesia
(Hasanah, 2020)	Assessing the effectiveness of STEM-based learning designed from an engineering viewpoint	Multi-method experiment	192 students	Indonesia
(Lippiello et al., 2025)	Investigating the relationship between pre-student performance and confidence	Quantitative design of pre-test – post-test	303 students	Italy

Data Analysis

The authors manually analyzed and synthesized 12 articles using thematic analysis methods (Nowell et al., 2017). The theme is determined based on the research questions. Based on RQ1, the theme set is a learning design that integrates physics-mathematics. Based on RQ2, the theme includes students' abilities that can be improved with a learning design that integrates physics-mathematics. Two independent coders extracted and coded the relevant data from each study. Initial coding was performed separately to minimize bias, after which the coders compared their codes and themes. Any discrepancies were resolved through discussion until consensus was reached. The finalized themes were then refined and synthesized to ensure consistency and alignment with the research objectives.

RESULTS AND DISCUSSION

Results

Table 2 presents research findings that include learning design, learning materials, and significance. Learning designs are very diverse. The STEM approach is most often found as the basis for learning development. In the context of learning materials, the integration of physics-mathematics shows mathematics as a tool to understand physics concepts. The significance is very diverse, but it will be dominated by the ability to think.

Table 2. Learning Design and Enhanced Capabilities

Author(s), Year	Learning Design	Material	Enhanced Capabilities
(Parno et al., 2020)	Problem-Based Learning (PBL) integrated with STEM approaches	Physics: The concept of optical tools Mathematics: Mathematical calculations	Science literacy skills
(Kokkonen et al., 2022)	The concreteness fading approach, which is a learning sequence from concrete → semi-iconic → abstract representations	Physics: The concept of electromagnetic induction Mathematics: Mathematical representations	Conceptual understanding
(Mafarja et al., 2024)	Cooperative Learning with Concept Mapping Assistance	Physics: Newton's concept of motion and laws Mathematics: Quantitative representation	Cognitive achievement
(Kotsalidis et al., 2024)	Case-based and cross-disciplinary approach through Exploring Molecular Modeling Activities (EMMAs)	Physics: The concept of force, energy, particle motion Mathematics: Numerical integration, atomic distance measurement, dynamics graph analysis	Conceptual understanding
(Lindner et al., 2019)	Interdisciplinary learning between geography and physics with project-	Physics: Electromagnetic spectrum, atmospheric physics, thermodynamics and	Conceptual understanding

	based approaches and digital experiments	urban heat radiation, astrophysics Mathematics: Measurement, histogram analysis, RGB classification, and calculation of surface temperature changes	and analytical skills
(Badru & Owodunni, 2021)	Integration of mathematical languages in science learning (physics, chemistry, biology)	Physics: the relationship of force, energy, and motion through mathematical expressions Mathematics: Mathematical concepts and scientific representations	Students' cognitive abilities in understanding and solving scientific problems
(Petersson, 2024)	Inquiry-based learning and cross-disciplinary group discussions (mathematics–physics)	Physics: Spring force and extension Mathematics: Linear regression model, $y=kxy = kxy=kx$	Mathematical creativity and conceptual understanding
(Altanis et al., 2018)	A game creation-based learning approach with a systematic game design and rapid development model using Kinect–Scratch integration (Kinect2Scratch)	Physics: Motion, angle, spatial 3D) Math: Geometry, coordinates, variables, programming logic	Computational thinking skills and spatial-geometric understanding
(Tang et al., 2020)	Collaborative STEM learning between Physics and Mathematics teachers through the Engineering Design Process (EDP) approach	<i>Physics</i> : Hooke's Law and elastic force <i>Mathematics</i> : Linear function $y=ax+by = ax + by=ax+b$	Cognitive and practical abilities
(Martawijaya et al., 2023)	Ethno-STEM-Project-Based Learning Model (Ethno-STEM-PjBL)	Physics: Concepts of force, acceleration, velocity, potential energy, angle of reflection, and fluid discharge Mathematics: Mathematical calculations	High order thinking skills
(Hasanah, 2020)	Engineering-based STEM system approach	Physics: Concepts of frequency, reactance, impedance, and resonance Mathematics: analysis of sinusoidal functions, e.g., phase relationships ($\pi/2$ radians)	Conceptual understanding and analytical-mathematical abilities
(Lippiello et al., 2025)	Integrative learning approach	Physics: force, energy, motion, electricity, and waves Mathematics: algebra, trigonometry, functions, graphs, and basic calculus	Confidence and performance

The integration of physics and mathematics learning can be conceptualized through five interrelated instructional design orientations that bridge conceptual understanding, representational transitions, and disciplinary collaboration (Table 3). This orientation collectively embodies the view that the learning of physics is inseparable from constructing and interpreting its mathematical representations. The language of mathematics provides the structure in which physical phenomena are modeled, while the physical context gives meaning to abstract symbols and equations. Therefore, effective instructional design should promote the reciprocal transfer between conceptual reasoning in physics and quantitative formulation in mathematics.

Table 3. Conceptualization of Learning Design and Competencies through Physics-Mathematics Integration

Main Categories	Learning Design	Integration Focus	Enhanced Capabilities
Problem–Project Integration	PBL-STEM, Ethno-STEM, EDP-STEM	Application of mathematical concepts & calculations in real projects	Scientific reasoning, engineering thinking
Representation–Transition Integration	Concreteness fading, Inquiry “curve fitting”	Transition from phenomena to mathematical models	Representational fluency, conceptual understanding
Cross-Disciplinary Integration	EMMAs, Geo-STEM, Math Language Integration	Connections between physics–mathematics–other sciences	Interdisciplinary reasoning, knowledge transfer
Tech–Creative Integration	Game-based (Kinect2Scratch), Digital experiment	Spatial logic, coordinates, motion simulation	Computational & spatial thinking
Cognitive–Affective Integration	Math language & confidence-based integration	Language, symbols, and self-confidence	Cognitive self-efficacy & symbolic literacy

Discussion

This study lays a solid foundation for informing learning interventions that integrate physics-mathematics in learning that offer significance to be applied in secondary schools. The current study identifies five learning design orientations and abilities that can be improved. These five orientations form a coherent conceptual framework for designing an integrated physics-mathematics learning environment. It considers that instruction is undergoing a shift, from procedural problem-solving to conceptual coherence, representational flexibility, and epistemic connections across disciplines. Such integrative design not only improves cognitive performance but also fosters

creativity, collaboration, and confidence, which are essential competencies for scientific literacy and problem-solving.

Physics-mathematics instructional design can be developed by integrating problem-based and project-based learning. Through the project cycle—defining, designing, experimenting, and evaluating—students relate the laws of physics (e.g., optics, mechanics, electricity) to mathematical modeling (functions, proportionality, measurements). This interconnectedness of experience strengthens scientific reasoning, engineering creativity, and analytical competence. The STEM approach is a real example in learning practice. Integrated STEM education often involves combining physics and mathematics within engineering design problems. For example, a module focused on building and heating a model passive house integrates physics and mathematics through problem-centered and cooperative learning (Goovaerts et al., [2019](#)). Another study highlights the integration of STEM project-based learning (PjBL) in improving students' achievements in various mathematical domains, although problem-solving showed less improvement compared to other areas (Han et al., [2016](#)).

Representation-Transition integration is in line with Bruner's representation mode, which includes active, iconic, and symbolic; which emphasizes cognitive development from concrete experience to abstract formulation (Bellon & Lowenthal, [2013](#)). This concept is crucial in understanding how individuals transition through different stages of cognitive development. The dynamic updating of representations and the integration of multiple properties highlight the complexity and importance of this cognitive process (Chang et al., [2021](#)). The transition from active to iconic to symbolic representations involves integrating different traits and forms of knowledge. This integration is fundamental in cognitive development and the learning process (Sakai et al., [2021](#)). Models such as concrete fading and the installation of inquiry-based curves encourage students to move smoothly between physical phenomena, visual models, and mathematical equations. This design fosters representational fluency, allowing learners to interpret graphs, formulas, and symbolic systems as coherent descriptions of physical reality.

Cross-Disciplinary Integration extends learning beyond the boundaries of a single subject. Cross-disciplinary learning involves the activation, transformation, and integration of resources from different disciplines to support sense-making in novel contexts (Borda et al., [2022](#)). This approach is not limited to physics and mathematics but can be applied across various fields to enhance learning outcomes. For example, case-based and inter-disciplinary programs – such as molecular modeling (EMMA), geophysics digital experiments, and the integration of mathematical languages into science – foster epistemic connections across domains. Another example in practical

application, the development of digital tools, such as the digital picture book on hydrogen energy, demonstrates how cross-disciplinary collaboration can improve student learning outcomes and stimulate positive responses to learning (Tang et al., [2025](#)). Similarly, the Concept Glancer prototype facilitates boundary crossing by visualizing bridging concepts, promoting collaboration and co-creation among students and lecturers (Spletter & Eppler, [2025](#)).

Tech–Creative Integration involves the convergence of computational modeling, digital simulation, and game-based design, especially in the fields of physics and mathematics. Computational modeling is used to create digital representations of physical phenomena, which can be manipulated and analyzed to understand complex systems. This is evident in the development of digital twins and simulations for a wide range of applications, such as manufacturing design and space operations (Lu et al., [2024](#)). In the context of education, computational modeling supports the integration of scientific concepts and computational thinking, especially in physics and mathematics (Clark & Sengupta, [2020](#)). Through digital simulations, virtual environments can be created to test and study mathematical models. This technology has evolved from mechanical simulations to advanced computer-based simulations used in fields such as filmmaking, engineering, and education (Wang, [2023](#)). For example, virtual reality (VR) and augmented reality (AR) are used to create engaging and effective learning tools (Gill et al., [2024](#)). Another effective approach to learning complex subjects such as physics and mathematics is game-based design, which integrates game elements to create an interactive and engaging learning experience (Schmidthaler et al., [2023](#)). Educational games, such as those designed to teach Newtonian mechanics or computational thinking, use game-based design to encourage collaboration, engagement, and a deeper understanding of scientific principles (Krinks et al., [2019](#)).

Cognitive–Affective Integration emphasizes the importance of learners' confidence and metacognitive awareness in effective physics and mathematics learning. Metacognitive awareness involves students' ability to reflect on and regulate their own learning processes. It includes knowledge about cognition (awareness of one's cognitive processes) and regulation of cognition (planning, monitoring, and evaluating one's learning strategies) (Chandaka & Manivasakan, [2025](#)). Studies have shown that metacognitive strategies can significantly enhance students' problem-solving skills and academic performance in mathematics and physics (Osman et al., [2025](#)). Confidence, or self-efficacy, is another critical factor influencing students' academic performance. Confidence in one's abilities can motivate students to engage more deeply with the material and persist through challenges (Bendol & Dalayap, [2025](#)). Research indicates

that students' confidence in mathematics and physics is positively correlated with their academic achievement and persistence in STEM pathways (Lippiello et al., [2025](#)).

Limitations

This systematic review research has several limitations. First, the literature search process is limited to only two scientific databases. This allows relevant studies to be indexed in other databases or grey literature were not captured. Second, the exclusion of relevant studies published other than in English raises the possibility of language bias. These limitations can affect the generalization of research findings. Therefore, future review research is recommended to use more databases, consider the inclusion of grey literature, as well as implement multilingual search strategies so that the synthesis of physics and mathematics integration is more comprehensive.

CONCLUSION

This systematic literature review provides a comprehensive overview of the various learning designs that can be applied in learning that integrate physics-mathematics and upskillful skills. Based on the analysis of 12 selected empirical research articles, learning designs that integrate physics-mathematics include five main categories, namely: problem-project integration, representation-transition integration, cross-disciplinary integration, tech-creative integration, and cognitive-affective integration. The application of learning shows a positive impact that is dominated on thinking skills.

Declaration on the Use of AI Statement

During the preparation of this work, the authors used AI tools to improve the readability and language of the manuscript. After using this tool, the authors carefully reviewed and edited the content as needed and take full responsibility for the content of the published article.

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