

## PHYSICS IN INTEGRATED STEM EDUCATION RESEARCH PROJECTS: A SYSTEMATIC REVIEW IN THE SECONDARY SCHOOL CONTEXT

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### ABSTRACT

**Background and Purpose:** This review explores the integration of physics into STEM (Science, Technology, Engineering, and Mathematics) education through project-based learning (PjBL) at the secondary school level. It aims to identify common types of integrated STEM projects for physics students and the physics concepts most frequently employed, addressing current gaps in the field.

**Methodology:** Guided by the PRISMA framework, this systematic review analyzed 20 peer-reviewed journal articles published within the last five years and indexed in the Scopus database.

**Findings:** The analysis revealed four main categories of physics-based STEM projects: Inquiry-Based Learning with Technology, Engineering Design Challenge Products, Electronic Module (E-module) Projects, and Abstract Problem-Solving Activities. Physics concepts related to momentum and Newtonian mechanics were most dominant, while thermodynamics, fluid mechanics, electronics, optics, and wave theory were underrepresented. Significant gaps identified include limited interdisciplinary integration, uneven physics content distribution, and inadequate resource availability.

**Contributions:** In response to these findings, a "5-Way Forward" framework is proposed to enhance the quality and impact of STEM project implementation in physics education. This review offers valuable insights for educators, curriculum developers, and policymakers to improve physics engagement in integrated STEM education and suggests directions for future research on long-term impact and teacher training.

**Keywords:** integrated STEM project, physics project, STEM education, physics education, secondary school.

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## **1.0 INTRODUCTION**

The global shift toward interdisciplinary learning has significantly elevated the importance of integrated Science, Technology, Engineering, and Mathematics (iSTEM) education, especially in secondary schools. STEM education is recognized not only as a critical pedagogical model for fostering problem-solving, innovation, and creativity but also as a strategic response to the growing demands of the 21st-century workforce (Honey, Pearson, & Schweingruber, 2014). In this context, physics, often considered abstract and difficult, plays a central role in STEM integration due to its foundational nature and broad applicability across scientific and technological disciplines (Beers, 2011; Moore et al., 2014).

Despite these potentials, integrating physics effectively into STEM projects remains a considerable challenge. Several studies report fragmented implementation, lack of conceptual coherence, and limited teacher preparedness (National Research Council, 2014; Margot & Kettler, 2019). Moreover, research frequently highlights the uneven representation of physics topics in iSTEM projects, with a predominant focus on Newtonian mechanics at the expense of equally critical domains such as thermodynamics, electromagnetism, optics, and modern electronics (Asrizal et al., 2022; Poor et al., 2023).

Given the centrality of physics in explaining real-world phenomena and supporting technological advancement, a nuanced understanding of how physics concepts are integrated into iSTEM projects is vital. Past literatures has focused on STEM pedagogy or science education in general, but a systematic synthesis of how physics is incorporated into secondary school iSTEM projects is notably absent. Addressing this gap is imperative, not only to inform curriculum design and teacher training but also to ensure that STEM integration supports deep disciplinary understanding and prepares students for future scientific pursuits.

This study presents a systematic review on iSTEM projects implemented at the secondary school level, with specific attention to the integration of physics concepts. It aims to address two research questions: (1) What are the common types of integrated STEM projects conducted for secondary school physics students? and (2) What physics concepts are most frequently addressed in these projects? By identifying dominant approaches and underrepresented areas, this review offers critical insights into the current state of physics education within integrated STEM initiatives and proposes recommendations for more balanced and effective implementation.

## **2.0 LITERATURE REVIEW**

### **2.1 Integrated STEM Education in the Secondary School Context**

To enhance effectiveness and engagement in learners' experiences, STEM education requires further advancements in implementation. Many educators worldwide are making an effort to assist their students by creating innovative teaching methods for STEM education, especially at the secondary school level. The implementation of specific pedagogies in STEM education may enhance cognitive outcomes (Khanaposhtani et al., 2018). Students can acquire new knowledge through direct engagement with nature and the application of authentic technology. Thus, the STEM learning experience becomes more engaging and dynamic.

Reviews indicated that the prevalent teaching method and strategies in STEM were project-based learning (PjBL) approaches, which contributed to STEM engagement and interest (McLure et al., 2022). A majority of educators concurred that the STEM project approach effectively develops and validates the learning environment, enhances conceptual knowledge, boosts student motivation, and fosters critical thinking skills, communication, and active learning (Dedetürk et al., 2021; De Meester et al., 2020; Govaerts et al., 2019).

The literature reveals a variety of STEM projects designed for secondary school physics students, mostly connected with real-world applications and hands-on learning. For example, projects involving renewable energy systems (e.g., designing solar panels or wind turbines) integrate physics concepts like energy conversion and thermodynamics with engineering and environmental science. Another common project type is bridge-building challenges (Andrew et al., 2022), which apply concepts of structural mechanics and material science to teach physics and engineering principles. These projects often emphasize collaborative learning, problem-solving, and the use of technology, aligning with the goals of iSTEM education. However, the literature also highlights challenges such as resource limitations, teacher preparedness, and the need for curriculum alignment, which can hinder the effective implementation of these projects (Thibaut et al., 2018).

## **2.2 Physics in STEM: A Critical yet Understudied Component**

Physics occupies a unique position in STEM as a discipline that underpins engineering design, technological innovation, and mathematical modelling (Dominguez et al., 2024). Its emphasis on quantitative reasoning and systems thinking makes it indispensable for cultivating 21st-century competencies (Chomphuphra et al., 2019). Yet, physics is frequently marginalized in integrated STEM curricula, overshadowed by biology and chemistry due to its perceived difficulty. Studies reveal that secondary students struggle with foundational physics concepts, such as force, energy, optics and electromagnetism, when taught in isolation from applied contexts (Rasheed et al., 2021).

Research suggests that engineering design challenges (e.g., constructing solar-powered devices) can bridge this gap by contextualizing physics principles (Dare et al., 2018). For example, Guzey et al. (2016) demonstrated that students who designed energy-efficient buildings showed an improved understanding of thermodynamics compared to peers in traditional instructional methods. However, such interventions often lack rigorous assessment of long-term conceptual retention, with gains sometimes fading post-intervention. This underscores the need for longitudinal studies to evaluate whether STEM-physics integration sustains impact beyond short-term engagement (Guzey & Li, 2023).

Nevertheless, teacher preparedness further complicates physics-STEM integration. Many educators lack training in interdisciplinary pedagogy, leading to reliance on siloed, textbook-driven instruction (Kanyesigye et al., 2022; Ismail et al., 2024). The study by Ismail et al. (2024) emphasizes the importance of teacher autonomy in implementing integrated STEM curricula, highlighting that teachers need the freedom to adapt and modify lessons to fit their classroom dynamics and student needs. This aligns with the National Research Council's findings that advocate for teacher autonomy as a critical component of successful STEM.

## **3.0 METHODOLOGY**

This study employed a systematic review methodology to identify, evaluate, and synthesise findings from peer-reviewed literature relevant to physics in iSTEM projects at the secondary school level. Following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Moher et al., 2009), the review was conducted in four sequential phases: identification, screening, eligibility, and inclusion (see Figure 1).

The initial identification phase was conducted using the Scopus database, selected for its comprehensive coverage of high-impact scientific publications. The search utilised a combination of terms including "Integrated STEM Education" and "Physics", producing a total of  $N = 1516$  articles. In the screening phase, inclusion criteria were refined to the subject area of "Social Sciences", narrowing the results to  $N = 802$ . Further filtering using the keyword "Physics" reduced the pool to  $N = 195$ .

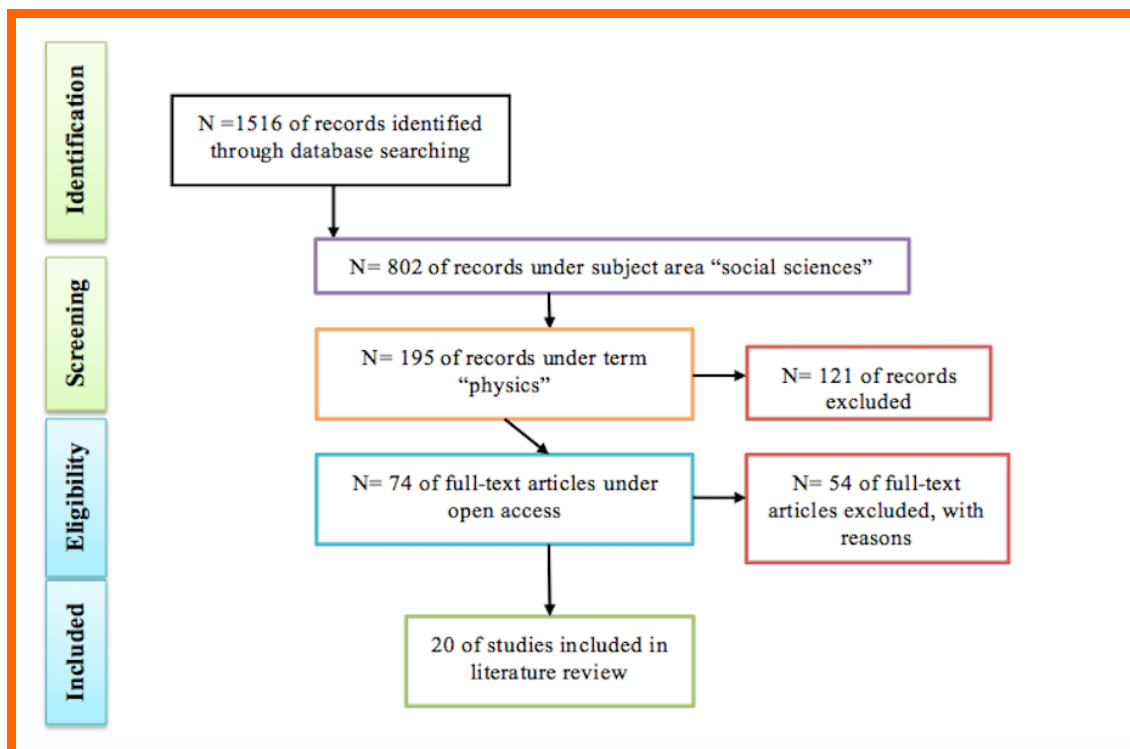


Figure 1: Flow of PRISMA information through the different phases of a systematic review

The eligibility phase imposed more stringent criteria, including only full-text, open-access, peer-reviewed journal articles published in English between 2018 and 2023. This resulted in a selection of N = 74 articles. During the final inclusion phase, a manual screening process was conducted. Each article's title, abstract, and research context were examined to ensure relevance to the secondary school context. Studies focusing on primary or tertiary education were excluded.

The selected studies were then analysed using constant comparison analysis, as described by Onwuegbuzie et al. (2012). This qualitative approach involved inductive coding to identify recurring themes and categories. An Excel spreadsheet was used to organise the extracted codes, which were subsequently synthesised into thematic clusters. These themes informed the structure of the Results and Discussion sections of this paper.

#### 4.0 RESULT AND DISCUSSION

A review of twenty journals across ten countries revealed a diverse distribution of studies on STEM projects for secondary education. Indonesia had the highest number of articles (n=6), followed by Malaysia (n=4). Portugal, Taiwan, the USA, and Belgium each contributed two studies, while Poland, Turkey, Norway, and Thailand each contributed one study. This distribution suggests a greater emphasis on STEM research in Southeast Asia, especially in Indonesia and Malaysia, compared to other regions examined in the review (see Figure 2).

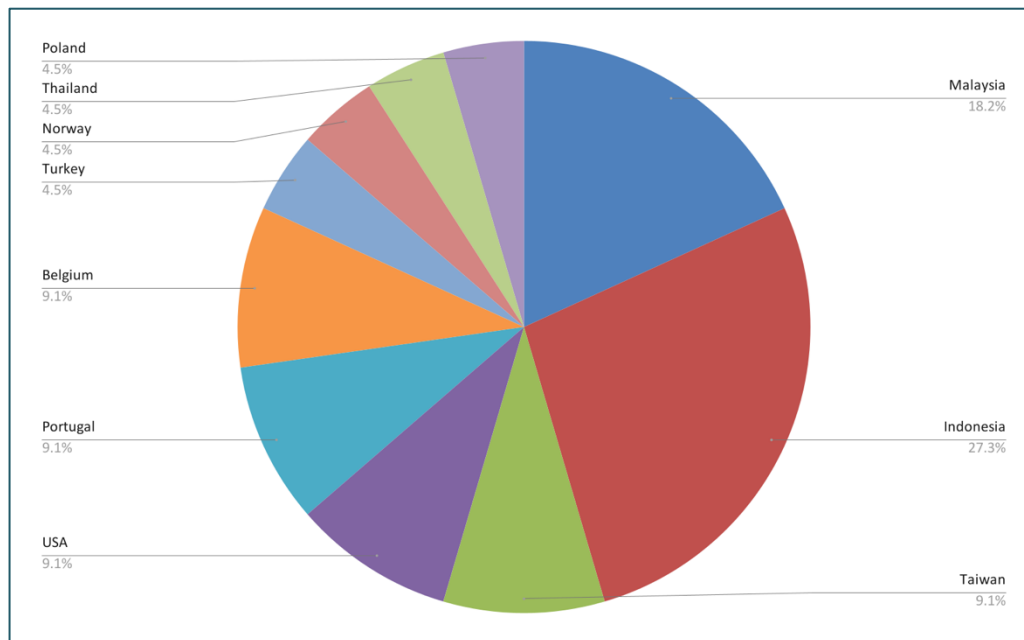


Figure 2: Countries' distribution in conducting the physics project research

The following Figure 3 illustrates the variation in publication years, focusing on studies from 2018 to 2023. The analysis of publication years reveals a fluctuating pattern in research output. In 2018 and 2020, there were three publications each, whereas in 2019, there were only one. A significant increase occurred in 2021, with seven publications, followed by a decline to two in 2022, and then a rise to four in 2023. This variation may be attributed to multiple factors, including changes in research funding, evolving research priorities in the field, or the impact of external events, including the COVID-19 pandemic in 2020 and subsequent years, on research activities. Additional examination of these potential influences may yield a more detailed comprehension of the observed publication trends.

The articles were published in sixteen distinct sources (see Table 1), highlighting the diverse range of publication sources. The distribution suggests a strong emphasis on physics education, particularly evident in the Journal of Physics: Conference Series, while other sources cover a broader range of disciplines. The variety of publication sources reflects widespread academic interest in the topic across multiple fields.

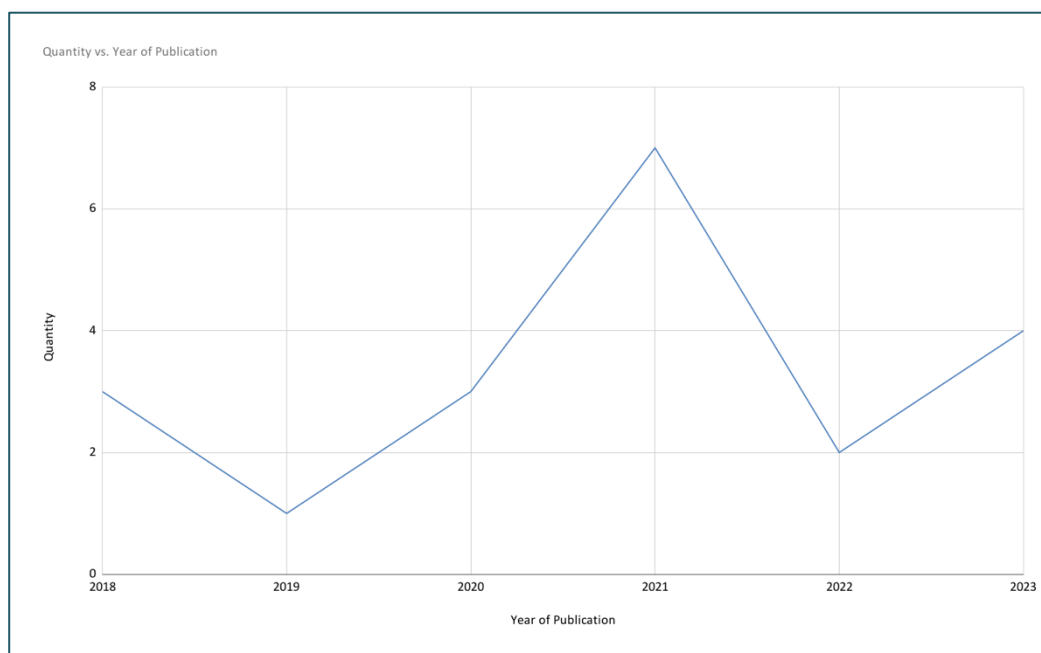


Figure 3: Publication year of the research articles

Table 1: List of publication sources in iSTEM projects

| No. | Sources  | Quantity |
|-----|--|----------|
| 1   | Journal of Physics: Conference Series                            | 4        |
| 2   | Sustainability   | 2        |
| 3   | International Journal of Emerging Technologies in Learning       | 1        |
| 4   | Jurnal Pendidikan IPA Indonesia                                  | 1        |
| 5   | International Journal of Technology and Design Education         | 1        |
| 6   | Cypriot Journal of Educational Sciences                          | 1        |
| 7   | AIP Conference Proceedings                                       | 1        |
| 8   | EURASIA Journal of Mathematics, Science and Technology Education | 1        |
| 9   | International Journal of STEM Education                          | 1        |
| 10  | European Review  | 1        |
| 11  | Journal of Baltic Science Education                              | 1        |
| 12  | European Journal of STEM Education                               | 1        |
| 13  | Learning, Culture and Social Interaction                         | 1        |
| 14  | Procedia Computer Science  | 1        |
| 15  | Frontiers in Psychology  | 1        |
| 16  | Interactive Technology and Smart Education                       | 1        |

#### 4.1 Integrated STEM Education in the Secondary School Context

This review identified prevalent integrated STEM (iSTEM) project types in secondary physics education by analyzing twenty articles. These projects were categorized into four main approaches based on their structure and focus: (i) Inquiry-based Learning with Technology (n=7), emphasizing student-driven investigation facilitated by digital tools; (ii) Engineering Design Challenge Products (n=5), centered on creating solutions to specific engineering problems; (iii) Electronic Modules (E-modules) (n=4), involving the development and

application of electronic circuits or systems; and (iv) Abstract Problem-Solving (n=2), focusing on tackling complex, often theoretical, challenges through interdisciplinary lenses. Two studies lacked sufficient detail for categorization. The following subsections compare the characteristics and findings within each category.

#### 4.1.1 Inquiry-Based Learning with Technology

Inquiry-based learning (IBL) integrated with technology is a significant pedagogical trend in secondary STEM, particularly physics. Table 2 synthesizes seven studies (Chen & Chang, 2018; Dare et al., 2018; De Meester et al., 2020; Santos et al., 2023; Mørch et al., 2023; Costa et al., 2023; Uden et al., 2023) that explore this integration to enhance student inquiry, conceptual understanding, and problem-solving. These studies generally report that this approach increases student engagement and deepens the connection between theoretical physics and real-world applications.

Table 2: Cross-comparison of the inquiry-based learning with technology projects

| Author' Code / Year /Country                         | Aim and Purpose  | Methodology  | Samples  | Research Findings  |
|--|--|--|--|--|
| 1. <b>Chen and Chang (2018) Taiwan</b>               | To develop a fully integrated STEM robotics curriculum using open software/hardware.   | Mixed-methods.   | 82 students<br>18 weeks.                                   | Experimental group showed significantly more positive iSTEM perceptions, enhanced knowledge, increased interest, and stronger career orientation.  |
| 2. <b>Dare et al. (2018) USA</b>                     | To explore the first-time experiences of nine science teachers' in implementing iSTEM curricular units..   | Phenomenological interpretive multiple-case study design         | 9 science school<br>3 weeks of Professional Development    | Three levels of iSTEM were identified (low, medium, and high) within curriculum implementation, with the degree of integration potentially linked to teachers' ability to establish meaningful STEM connections.       |
| 3. <b>De Meester et al. (2020) Belgium</b>           | To develop an approach and curriculum for iSTEM education in Flanders and to assess its effects on students' performance and attitudes towards STEM.       | Design-based, Quasi-experimental methodology.                    | Grade 9-12 students from 38 schools.<br>+Duration: 4 years | 1. iSTEM Learning Units should be standards-based and should address five key principles.<br>2. Students' collective classroom engagement increased during lessons due to the high level of student-centredness.       |
| 4. <b>Santos et al. (2023) Poland &amp; Portugal</b> | To present the Partnerships for Science Education (PAFSE) project, and to explore how the project-based learning engaged students in public health topics. | A case study   | Secondary students.  | The PAFSE project demonstrates that PjBL effectively engages students in public health topics, enhancing their critical thinking and scientific literacy. Furthermore, it prepares students for real-world challenges. |
| 5. <b>Costa et al. (2023) Portugal</b>               | To conduct hands-on activities on the topic of sound in the classroom, aiming to equip students with 21st-century skills                                   | A mixed-method: Questionnaires & Observation with interpretative | 26 teachers & 63 students                                  | The workshops enhanced teachers' and students' understanding of noise pollution, awareness, and its health impacts significantly. Indicates the  |

|   |  |                           |  |                     |   |
|---|--|---------------------------|--|---------------------|---|
|   | relevant to STEM education.  | approach                  |  |                     | effectiveness of educational strategies in promoting the Sustainable Development Goals (SDG) through STEM activities.   |
| 6. Mørch et al. (2023) Norway           | To familiarise students with electronics, computer programming, and other makerspace equipments.                             | Exploratory case study.   | 17 students  | +Duration: 16 weeks | The approaches in projects effectively enhance students' understanding of scientific concepts. Key themes identified include engagement through spontaneous concepts, programming, and the integration of subject learning. |
| 7. Uden et al. (2023) Malaysia & Taiwan | The goal is to enhance students' physics learning by developing the iSTEM-PjBL method based on principles from neuroscience. | Quasi-experimental design | 77 control and 77 experiment al group of students from Malaysia & Korea. | +Duration: 8 weeks  | The study found that the integrated STEM-PjBL approach significantly improved students' beliefs about physics and their learning experiences in both Malaysian and Korean contexts.   |

The "Green Wave Car Project" (De Meester et al., 2020), integrating physics, engineering, and computational thinking, exemplifies IBL with technology. Its emphasis on hands-on experimentation, iterative design, and problem-solving aligns with IBL principles, engaging students with practical physics concepts like acceleration and velocity in real-world STEM contexts. However, a key question remains whether such structured projects genuinely foster inquiry or guide students toward predetermined outcomes. Furthermore, the extent to which students develop fundamental physics understanding versus focusing on technical execution requires further investigation.

Uden et al. (2023) offered a novel contribution by incorporating neuroscience insights into STEM PjBL, suggesting that cognitive processes can positively influence STEM education, particularly conceptual retention and problem-solving. Nevertheless, the empirical link between neuroscience and STEM education is still nascent. We suggest conducting more rigorous studies to answer questions like: Which cognitive processes will STEM PjBL most successfully activate? To what extent do pedagogies guided by neuroscience perform better than more conventional STEM approaches? In what educational and cultural setting is this neuroscience insight scalable?

Overall, while IBL with technology demonstrates promising outcomes, several research gaps persist concerning inquiry structures, accessibility, scalability, and longitudinal impact. A recurring challenge is determining the optimal balance between teacher guidance and open-ended inquiry. Future research should investigate the minimal scaffolding needed to support student autonomy without limiting creativity and address digital equity in technology access. The scalability of neuroscience-driven approaches also requires more empirical validation to understand how cognitive science can broadly inform STEM pedagogy. Additionally, longitudinal studies are needed to assess the long-term effects of IBL with technology on conceptual retention and career readiness, as current studies primarily focus on short-term engagement and performance.

### 4.1.2 Engineering Design Challenge Product

The Engineering Design Challenge Product (EDCP) effectively fosters practical engineering skills, real-world application of theory, and problem-solving abilities in STEM. Table 3 synthesizes five studies (Rahman et al., 2021; Dedetürk et al., 2021; Goovaerts et al., 2018; Parno et al., 2020; Rugh et al., 2021) that investigated EDCP's impact on student learning, conceptual understanding, and STEM engagement through methodologies like PjBL and quasi-experimental designs. These studies generally show that allowing students to design, evaluate, and refine their product outputs enhances creativity, collaboration, and critical thinking (Roehrig et al., 2021), contributing to deeper learning and problem-solving in physics.

Table 3: Cross-comparison of the engineering design challenge product

| Scholars' Code / Year / Country     | Aims and Purpose  | Methodology   | Samples                                 | Research Findings  |
|-------------------------------------|---|---|---|--|
| 8. Rahman et al. (2021) Malaysia    | To support the preparation and implementation of innovation for informal science learning.  | Quantitative: Survey using Post & pre-test.                                       | 349 students<br>Duration: 2 Days        | Most of the students did have an initial idea of physics concepts. However, their ability to make inference and observation is weakly correlated and not significant.  |
| 9. Parno et al. (2020) Indonesia    | To investigate the empirical evidence which shows that PBL-STEM integration has an impact on students' scientific literacy                              | Quasi-experiment non-equivalent group design                                      | -99 Students<br>Duration: 6 weeks       | Scientific literacy competencies domain of PBL-STEM was the highest, while PBL class is higher than the control class.   |
| 10. Dedetürk et al. (2021) Turkey   | To examine the effects of engineering design process-oriented STEM activities, which were developed for sound concept.                                  | Comparative case study  | 40 students + Duration: Spring Semester | The students' level of conceptual understanding in experimental group were more positive than control group.   |
| 11. Goovaerts et al. (2018) Belgium | To motivate students in STEM field, a teaching approach with a focus on integration of physics & mathematics into engineering design component of STEM. | Research Design + Meetings with the teachers and questionnaires.                  | +4th-year Flemish students;             | This learning module has covered all curriculum guidelines concerning heat. The approach requires more time investment but involves a deeper learning of the concepts. |
| 12. Rugh et al. (2021) USA          | To examine a STEM-PjBL activity that integrates technology & the EDP to teach students the concepts of rotational physics.                              | Case Study: the dynamic & interactive mathematical expressions (DIME) map system. | 34 physics students<br>Duration: 5 days | The DIME map helped students make connections between concepts, while the STEM-PjBL helped students make connections from concepts to experiences and observations.    |

Despite EDCP's promise, several implementation, assessment, and scalability challenges remain. A key issue is the gap between students' theoretical knowledge and their ability to apply it practically. Rahman et al. (2021) found that while students had initial physics concept

understanding, they struggled with inference and observation, suggesting that brief EDCP exposure may not guarantee deep conceptual understanding. This raises questions about how to better scaffold instruction to improve learning outcomes. Furthermore, while EDCP correlates with increased engagement, its impact on long-term retention of STEM concepts is underexplored.

Rahman et al. (2021) also noted that iterative design cycles (brainstorming, prototyping, testing, refining) enhanced creativity and problem-solving. However, their findings suggest that active engagement alone isn't sufficient for knowledge transfer, as students still faced difficulties with inferential reasoning and observation, potentially highlighting a reliance on prior IBL experience. Additionally, the influence of cultural and contextual factors on EDCP participation warrants further study, as effective practices in well-resourced settings might not translate to underprivileged schools.

Goovaerts et al. (2018) demonstrated the value of linking engineering principles to product design through a house heating system model project. This study highlighted students' ability to translate physics concepts into mathematical expressions, use data analysis software, and develop engineering models visually. A central challenge in EDCP, however, is ensuring the development of both technical competence and a deep conceptual understanding of STEM principles. Beyond physics applications, the study emphasized mathematical modelling and technological integration, raising important inquiries such as whether EDCP fosters stronger analytical reasoning than traditional STEM education, how digital tools affect conceptual model development, and how project complexity influences engagement and motivation.

In summary, while EDCP is an effective strategy promoting active, student-centered learning, iterative problem-solving, and interdisciplinary integration, its success depends on factors like prior knowledge, teacher preparedness, time constraints, resources, and curriculum alignment. Although existing studies are valuable, more research is needed on effective adaptation and scaling of EDCP across diverse educational contexts. Addressing these research gaps is crucial for validating EDCP as a systematic framework to enhance global STEM learning outcomes.

### ***4.1.3 E-Module Projects***

The integration of E-Module projects is another common iSTEM approach, aimed at enhancing student engagement, digital literacy, and cognitive skills. Table 4 synthesizes four studies (Asrizal et al., 2022; Purwaningsih et al., 2021; Handayani et al., 2021; Zahara et al., 2021) that explored the development, implementation, and impact of E-Modules in physics education. These studies employed various methodologies, including post-test-only experimental designs and mixed-methods approaches, focusing on instructional elements like critical and creative thinking, and augmented reality integration.

Table 4: Cross-comparison of the E-Module projects

| Scholars' Code / Year / Country                 | Aims and Purpose   | Methodology                                  | Samples                                    | Research Findings  |
|---|--|--|--|--|
| <b>13. Asrizal et al. (2022) Indonesia</b>      | To investigate the effectiveness of the physics electronic teaching material-iSTEM education (PETMS) in improving students' 21st-century skills. | Experimental study.                          | 66 students<br>Duration: 5 meetings        | The electronic teaching material is better at achieving student learning outcomes in the knowledge aspect than the publisher textbook.                                       |
| <b>14. Purwaningsih et al. (2021) Indonesia</b> | To improve physics students creative thinking skills by worksheet learning.  | Research and Development (ADDIE design)      | 15 physics students<br>12 lesson hours.    | An effective improvement in student's creative thinking skills after experiencing learning using worksheet.  |
| <b>15. Handayani et al. (2021) Indonesia</b>    | To develop learning media in the form of electronic modules for students on critical-thinking skills.  | Quantitative: Questionnaires                 | 26 physics students                        | iSTEM physics E-Module needed to be equipped with quizzes and questions to train students' critical-thinking skills.   |
| <b>16. Zahara et al. (2021) Indonesia</b>       | To analyze teacher and students' perceptions of augmented reality (AR)-assisted worksheets with iSTEM approach in physics learning.              | Mixed method (questionnaires and interviews) | 139 physics students & 16 physics teachers | Teachers have not fully used AR-based teaching materials STEM approach. Students & teachers need electronic worksheets assisted by 3D animation using AR and iSTEM approach. |

Purwaningsih et al. (2021) investigated STEM-oriented E-Module worksheets to enhance creative thinking in optics. The study indicated that E-Modules promote originality, fluency, flexibility, and elaboration, encouraging practical application of information. However, the small sample size (n=15) and focus on optics limit generalizability. Future research should explore if E-Modules yield similar cognitive benefits across other STEM fields and with more diverse student groups. Additionally, the study did not examine the role of instructor guidance. While E-Modules encourage autonomy, students might struggle with complex topics without adequate support, raising the question of the optimal balance between digital autonomy and teacher direction.

Handayani et al. (2021) focused on an iSTEM physics E-Module to improve critical thinking, aligning with the trend of using digital modules for both educational resources and cognitive skill development. However, the study has limitations: a lack of focus on long-term effects, a small and potentially unrepresentative sample, and a reliance on questionnaire-based feedback, which may not fully capture critical thinking development. Future studies should employ longitudinal designs, larger and more diverse samples, and performance-based assessments to enhance the validity and reliability of E-Module research.

Collectively, the findings support the effectiveness of E-Modules in fostering 21st-century skills. However, the long-term impact on conceptual retention and problem-solving remains largely unassessed, with most research highlighting short-term gains. Furthermore,

while E-Modules can boost engagement, their effectiveness heavily relies on students' digital literacy and access to technology, raising equity concerns in under-resourced settings.

#### 4.1.4 Abstract Problem-Solving Activities

Abstract Problem-Solving Activities (APSA) represent another STEM pedagogical approach, emphasizing cognitive engagement, analytical thinking, and the theoretical application of scientific concepts. Unlike IBL with technology or EDCP, APSA prioritizes conceptual problem-solving, abstract reasoning, and advanced cognitive skills over tangible outputs. Table 5 outlines two studies (Rasheed et al., 2021; Simeon et al., 2020) that utilized APSA in physics STEM learning, demonstrating its potential to enhance abstract reasoning, problem-solving abilities, and digital engagement.

Table 5: Cross-comparison of the abstract problem-solving projects

| Scholars' Code / Year /Country     | Aims and Purpose   | Methodology                              | Samples   | Research Findings   |
|------------------------------------|--|--|---|---|
| 17. Rasheed et al. (2021) Malaysia | To assess the effectiveness of virtual laboratories.   | Quantitative: Experiment – control group | 184 physics students                                | Students' learning was increased by using virtual laboratories.   |
| 18. Simeon et al. (2020) Malaysia  | To investigate the effect of using a design thinking teaching method on students' achievement of physics concepts. | Quasi-experiment.                        | 48 male students and 41 female students<br>12 weeks | Both male and female students improved in their achievements. Male participants had higher achievement scores than the females when STEM-design thinking modules were used. |

Rasheed et al. (2021) highlighted the benefits of virtual laboratories, finding increased student engagement and motivation compared to traditional labs. Virtual labs allow for repeated experimentation, real-time variable manipulation, and application of scientific principles in a simulated setting. However, this raises questions about whether virtual labs adequately develop the practical skills needed for authentic scientific experimentation, how their effectiveness compares to real-world physics experiments where practical dexterity is important, and if an entirely digital environment might lead to a loss of essential procedural and observational skills. Furthermore, the study doesn't address the equitable access to virtual laboratories, particularly for students in rural areas with limited access to digital technology, potentially creating disparities in participation.

Thus, despite its advantages, APSA presents challenges regarding inclusivity, effectiveness, and scalability. A key concern is whether APSA is equally effective across diverse learners, especially those who struggle with abstract learning. Additionally, while APSA fosters cognitive flexibility, it might lack the hands-on practical engagement often central to iSTEM. This raises the question of whether APSA primarily develops problem-solving skills without necessarily reinforcing concrete scientific understanding.

#### 4.1.5 Uncategorized Projects

Two studies (Bao et al., 2019; Saputri et al., 2022), detailed in Table 6, lacked sufficient information to be categorized by project type, indicating potential reporting inconsistencies or varied research foci. Saputri et al. (2022) explored the integration of PjBL with iSTEM to enhance creative thinking in secondary physics (momentum and impulse). While the study

reported improved creative thinking, its findings are limited by the short intervention period (three meetings), which raises concerns about the long-term sustainability of these gains.

Furthermore, the absence of specific sample size and demographic data limits the generalizability of the results. Critically, the study focused solely on creativity, without assessing the impact on the understanding of underlying physics principles. The lack of a control group or comparison with other instructional methods (like IBL or traditional teaching) also makes it difficult to attribute the observed improvements directly to the PjBL-iSTEM approach. Future research should include longitudinal assessments, detailed sample information, content-based evaluations, and comparative analyses to better determine the effectiveness of PjBL-iSTEM in fostering both creativity and conceptual understanding.

Table 6: Cross-comparison of the uncategorised projects

| Scholars' Code / Year / Country     | Aims and Purpose   | Methodology                           | Samples               | Research Findings   |
|-------------------------------------|--|---------------------------------------|-----------------------|---|
| 19. Saputri et al. (2022) Indonesia | To analyze students' creative thinking skills on momentum and impulse material through PjBL iSTEM      | Quasi experiment                      | Class X<br>3 meetings | The average value of students' creative thinking skills are classified as creative category.  |
| 20. Bao et al. (2019) Thailand      | To design the process of teaching some STEM-oriented contents of "Magnetic field" in Physics Grade 11. | Phenomenological, interpretive design | 28 students           | The STEM-oriented teaching process creates excitement for students, develop the 21 <sup>st</sup> -century skills and abilities as well as equipped students with the basic knowledge. |

Bao et al. (2019) reported increased student enthusiasm and interdisciplinary learning with iSTEM. However, the study did not evaluate long-term knowledge retention or conceptual understanding, focusing instead on engagement and skill development. The absence of post-intervention data on knowledge application leaves the impact of deep learning unclear. Additionally, the interpretive design, lacking a control group, complicates drawing causal links between the iSTEM instruction and the observed outcomes. The study also lacked specifics on the disciplines integrated and the depth of their connection, making it difficult to ascertain if a truly holistic STEM perspective was achieved. Notably, the study did not assess whether students' conceptual understanding of magnetic fields improved compared to traditional methods. Future research should incorporate assessments of conceptual understanding alongside engagement metrics and employ comparative designs to rigorously evaluate the academic impact of iSTEM instruction.

#### 4.2 The Most Common Physics Concepts Employed

To address the second objective, the physics concepts within the reviewed iSTEM projects were mapped against the Malaysian Secondary School Standard Curriculum (KSSM) physics syllabus (revised 2020). Table 7 categorizes the identified concepts under the syllabus's main topics: Measurement, Force and Motion, Heat, Wave, Light and Optics, Forces and Motion II, Pressure, Electricity, and Electronics.

Table 7: Topic of physics concepts employed in iSTEM project

| Topic / Total Study         | Concept of Physics                              | Scholar's Code                         |
|-----------------------------|---|--|
| Measurement / 1             | Use of Scientific Measurement and devices       | (8)                                    |
| Force and Motion<br>/ 11    | Linear motion                                   | (8) (17) (18) (3) (11) (4)             |
|                             | Free Fall motion                                | (17) (7) (12)                          |
|                             | Newton first law (Inertia)                      | (18) (7) (20)                          |
|                             | Momentum  | (8) (17) (19) (3)<br>(4) (18) (7) (20) |
|                             | Newton second's Law (Force, Mass, Acceleration) | (17) (18) (11) (7)(12) (20)            |
|                             | Impulse   | (18);(19); (4);(7) (20)                |
| Heat / 4                    | Thermodynamics; Heat Transfer                   | (15); (2); (11); (7)                   |
| Wave<br>/ 2                 | Vibration and Wave Topic                        | (5)                                    |
|                             | Sound   | (10)                                   |
| Light & Optic / 2           | Optical Instrument.                             | (9); (14)                              |
| Forces and Motion II<br>/ 6 | Elasticity material                             | (13)                                   |
|                             | Force and Motion II (Works, Energy & Power)     | (1) (4) (7), (12) (20)                 |
| Pressure<br>/ 3             | Fluid Mechanics, density, weight                | (8) (1) (11)                           |
|                             | Archemedes Principle                            | (8) (1)                                |
| Electricity<br>/ 5          | Magnetic Field: Electromagnetic Induction       | (1)                                    |
|                             | Electric  | (1)(10) (11) (6)                       |
|                             | Electrostatic                                   | (16)                                   |
| Electronics / 3             | Electron, Semiconductor, Diode                  | (5)(6) (11)                            |

As detailed in Table 7, the analysis reveals a significant prevalence of "Momentum", "Linear Motion, and "Newton's Second Law", indicating that the domain of Force and Motion (encompassing 11 studies) is the most frequently addressed in iSTEM projects. This emphasis on Newtonian mechanics likely stems from its foundational role, the ease of hands-on demonstrations, and direct relevance to engineering problem-solving (Dvorak et al., 2016). While mastery of Newtonian mechanics is crucial, its dominance may lead to the underrepresentation of other vital areas like electromagnetism, optics, and wave mechanics, which are central to modern technologies. Future iSTEM projects should aim for a more balanced integration of these contemporary physics domains to better align with 21st-century technological demands.

Despite its fundamental nature, Newtonian mechanics poses conceptual challenges for students (Nassiri, 2012), often exacerbated by a lack of hands-on experimentation in traditional teaching. While iSTEM projects attempt to address this through active learning, the long-term impact on the retention and interdisciplinary application of Newtonian concepts warrants further investigation, particularly in emerging fields like biomechanics and robotics.

Electricity is another fundamental concept appearing in iSTEM projects, albeit less frequently than Newtonian mechanics. Concepts such as resistance, conductivity, and current are core to both science and engineering (Poor et al., 2023), essential for understanding modern electrical and electronic technologies. The relative underrepresentation of electricity might be due to its conceptual complexity and the need for specialized (and potentially less accessible) components (Asrizal et al., 2022). Future research should focus on developing cost-effective and scalable resources to better integrate electrical concepts into iSTEM projects, exemplified by applications in robotics and sustainable energy.

Thermodynamics, heat transfer, and pressure concepts are notably underrepresented despite their real-world significance in areas like energy systems and climate science (Hojjat & Keshtkar, 2025). Similarly, fluid mechanics principles have limited coverage (Dewi et al., 2019), restricting students' exposure to topics crucial for diverse fields. This underrepresentation may be due to the abstract nature of these topics, the need for specialized resources, and potentially educators' comfort levels (Dare et al., 2018). Future iSTEM initiatives could leverage computational modelling and simulations to enhance engagement

with these areas and explore real-world applications like sustainable building and biomedical systems.

Electronics and advanced STEM applications also show limited integration. Despite the growing relevance of electronics in automation, robotics, and AI (Zhao et al., 2021; Ismail et al., 2025), related iSTEM projects are scarce. Future initiatives should prioritize incorporating microcontroller-based projects to better prepare students for careers in these fields.

Furthermore, many iSTEM projects lack a strong interdisciplinary approach, often focusing on single-discipline physics concepts (Dare et al., 2018). Real-world STEM problems necessitate integrated knowledge. Future projects should actively incorporate interdisciplinary approaches, such as combining physics with computational modeling, to equip students with the skills needed to tackle complex global challenges.

Finally, wave and light/optics concepts are less explored, possibly due to the need for complex experimental setups (Dvorak et al., 2016). To enhance student engagement, digital tools and simulations could be valuable, alongside exploring interdisciplinary applications like medical ultrasound and quantum photonics.

### 4.3 A 5-Way Forward for Physics in STEM Education

Analysis of current iSTEM implementations reveals critical gaps in physics education needed to equip students for future STEM challenges. Moving beyond the traditional focus on Newtonian mechanics is crucial to reflect the breadth of 21st-century physics. To foster a more comprehensive and future-oriented physics STEM curriculum, five strategic pathways are essential:

- i. **Expand Beyond Newtonian Mechanics.** While foundational, the strong emphasis on Newtonian mechanics in iSTEM projects underrepresents electromagnetism, optics, and wave mechanics, integral to modern technologies (Poor et al., 2023) such as fiber optics, GPS, stealth aircraft, CAT scans, LCDs, and LEDs (Henrich, 2018). Future curricula should integrate these areas through interdisciplinary projects exploring the electromagnetic spectrum and wave phenomena (Kotsis, 2024).
- ii. **Incorporate Modern Physics Topics.** Modern physics (quantum mechanics, relativity, particle physics) is largely absent from secondary iSTEM, despite its significance in scientific advancements. Simplified models and simulations can introduce these topics, bridging classical and modern physics and sparking interest in future-oriented fields (Chen & Chang, 2018; Santos et al., 2023).
- iii. **Prioritize Thermodynamics and Fluid Mechanics.** Underutilized despite their relevance in engineering, environmental science, and energy (Uden et al., 2023), thermodynamics and fluid mechanics can be made more accessible through computational modeling (Goovaerts et al., 2018). Projects exploring energy efficiency and renewable energy applications can provide practical experience.
- iv. **Advance Electronics Integration.** Despite the prevalence of electronics in automation, robotics, and IoT, it is often overlooked in iSTEM (Zhao et al., 2021; Asrizal et al., 2022). Integrating low-cost microcontroller projects such as Arduino or Raspberry Pi (Hambali et al., 2024) can offer practical engagement with electronics, preparing students for AI-enhanced systems (Poor et al., 2023).
- v. **Embrace Interdisciplinary Learning.** To reflect real-world STEM complexities, future projects should move beyond single-discipline physics and integrate computational modeling, AI, and data science (Simeon et al., 2020; Dedetürk et al., 2021; Mørch et al., 2023). Interdisciplinary problem-solving fosters deeper learning and broader skill sets.

## 5.0 CONCLUSION

This systematic review examined the integration of physics in STEM education research projects at the secondary school level. The predominance of Inquiry-Based Technology (IBT) and Engineering Design Challenges (EDC) underscores a pedagogical shift toward active learning. These challenges highlight a disconnect between iSTEM's interdisciplinary ideals and its practical execution, often reducing physics to a supplemental role rather than a foundational pillar. In addition, the analysis of 20 studies revealed that Newtonian mechanics, particularly momentum, linear motion, and Newton's laws, dominates iSTEM projects, reflecting their hands-on applicability and alignment with traditional curricula. While these projects enhance engagement and problem-solving skills, their overreliance on classical physics topics risks neglecting modern and interdisciplinary applications, such as quantum mechanics, electronics, and thermodynamics, which are critical for twenty-first-century STEM literacy. Finally, the review suggests five ways forward to foster a more comprehensive and future-oriented physics STEM curriculum.

## 6.0 LIMITATION

This study has three methodological constraints which are: i. Database Restriction: While Scopus ensures quality, excluding WoS or ERIC may have omitted relevant studies, particularly from non-English contexts (e.g., Japan innovations in low-cost STEM projects); ii. Temporal Bias: The 5-year publication window (2018–2023) prioritizes recent trends but may overlook foundational studies on longitudinal impacts of iSTEM; iii. Contextual Specificity: 60% of analyzed studies were from Southeast Asia (e.g., Malaysia, Indonesia), potentially skewing findings toward regional pedagogical preferences (e.g., emphasis on exam-aligned mechanics topics). Hence, future reviews could employ cross-database searches and extend timeframes to mitigate these limitations.

## 7.0 IMPLICATIONS

Future studies should prioritize longitudinal designs to assess whether iSTEM projects lead to sustained physics mastery and career readiness. Additionally, research may explore: i. Modern Physics Integration: How quantum mechanics, relativity, and photonics can be adapted for secondary-level iSTEM without sacrificing rigor (Krijtenburg-Lewerissa et al., 2017); ii. Interdisciplinary Synergies: The role of computational modeling and AI in bridging physics with other STEM disciplines (e.g., bioengineering, climate science) (Poor et al., 2023). In terms of educational practices, educators and curriculum developers may implement: i. Diversify Project Topics: Incorporate underrepresented physics domains (e.g., thermodynamics, electromagnetism) through low-cost simulations or partnerships with local industries (Asrizal et al., 2022); ii. Enhance Teacher Training: Professional development programs must equip teachers with strategies to scaffold abstract concepts (e.g., using augmented reality (AR) for quantum physics) and facilitate equitable group work (Kanyesigye et al., 2022; Ismail et al., 2024).

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