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The Influence of STEM-Oriented Physics Instruction on Students' Scientific Reasoning and Learning Motivation

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KEYWORDS
STEM Instruction, Scientific Reasoning, Learning Motivation.

ABSTRACT
Students' low scientific reasoning skills and reduced motivation to learn physics remain persistent challenges in secondary education. Traditional instruction often emphasizes memorization and formula-based problem-solving, resulting in limited conceptual understanding and weak engagement. To address these issues, STEM-oriented learning has been proposed as an instructional approach that integrates science, technology, engineering, and mathematics to promote authentic inquiry, problem-solving, and real-world application. This study aims to analyze the influence of STEM-oriented physics instruction on students' scientific reasoning and learning motivation through a qualitative literature study. Data were obtained from scholarly journal articles, books, and research reports published within the last ten years, selected purposively for relevance and credibility. Using content analysis, the literature was reviewed to identify thematic patterns related to STEM implementation, its cognitive effects, and its motivational outcomes. The findings indicate that STEM-oriented physics instruction significantly enhances scientific reasoning by engaging students in hands-on experimentation, engineering design cycles, and technology-supported inquiry. These activities promote hypothesis testing, evidence-based argumentation, and iterative problem-solving, which are core components of scientific reasoning. Additionally, STEM learning fosters increased motivation by situating physics concepts in meaningful real-world contexts, providing collaborative problem-solving opportunities, and integrating interactive technological tools. Students become more engaged, confident, and persistent in tackling physics tasks. Overall, STEM-oriented instruction demonstrates strong potential to improve both cognitive and affective learning outcomes in physics education. The study highlights the need for coherent instructional design, effective teacher preparation, and structured assessment aligned with STEM practices to maximize its impact.

1. INTRODUCTION

Physics learning in secondary schools continues to face various challenges, particularly related to students' low scientific reasoning skills, which serve as the foundation for scientific thinking and problem-solving (Bybee, 2013). This condition is exacerbated by instructional practices that still emphasize memorizing concepts and solving mathematical formulas without encouraging deeper conceptual exploration (Hake, 1998). Many students struggle to connect real-world phenomena with physical principles, making the learning process less meaningful (Redish & Burciaga, 2003). As a result, twenty-first century competencies such as critical thinking, collaboration, creativity, and scientific reasoning have not yet developed optimally in physics learning (Council et al., 2012).

In addition to scientific reasoning, students often

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report low motivation to learn physics due to the perception that physics is a difficult and abstract subject (Glynn et al., 2011). Low motivation negatively affects students' engagement during the learning process and weakens their efforts to develop a deep understanding of physics concepts (Pintrich & De Groot, 1990). Classroom environments that are insufficiently stimulating and fail to provide hands-on learning experiences further worsen this condition (Deci & Ryan, 2000). Therefore, it is necessary to implement learning approaches capable of enhancing students' intrinsic motivation and engagement in learning physics (Tohidi & Jabbari, 2012).

STEM-oriented learning (Science, Technology, Engineering, and Mathematics) is a strategic instructional alternative to address these issues because it integrates interdisciplinary concepts that emphasize authentic problem-solving (Sanders, 2008). STEM-based instruction encourages students to design, test, and evaluate technology-based solutions, enabling them to develop scientific reasoning skills in real-world contexts (Schweingruber et al., 2014). The integration of experimental activities, engineering design, and technology in STEM learning has been widely shown to improve students' higher-order thinking skills (English, 2016). Thus, STEM-oriented physics instruction has strong potential to improve the quality of learning processes while strengthening applied conceptual understanding (Anderson, 2020).

Beyond enhancing scientific reasoning, previous studies indicate that STEM learning also positively affects students' learning motivation by providing learning experiences that are relevant to real-life situations (Wang, 2013). Project-based activities in STEM learning make students more active, motivated, and challenged to solve contextual problems (Capraro et al., 2013). The use of technological tools and interactive media in STEM approaches further strengthens students' interest in science, including physics (Osborne & Dillon, 2008). Through holistic integration of concepts, STEM learning promotes social interaction, exploration, and creativity, thereby facilitating optimal improvement in students' learning motivation (Morrison, 2006).

Although STEM-oriented instruction has been widely recommended in educational policy, its implementation in physics classrooms remains limited and has not been comprehensively evaluated, especially regarding its impact on scientific reasoning and learning motivation (Zollman, 2012). The lack of contextualized studies at the secondary school level has resulted in insufficient confirmation of the effectiveness of this approach within Indonesian physics education contexts (Nugroho et al., 2021). Therefore, research examining the influence of STEM-oriented physics learning on students' scientific reasoning and learning motivation is essential as a foundation for developing more effective instructional models (Rahmawati et al., 2023).

A number of studies have shown that STEM implementation can improve learning outcomes, problem-solving abilities, and student creativity (Becker & Park, 2011). Other research highlights that the integration of STEM can strengthen scientific reasoning through linked experimental and engineering design activities (Anwar et al., 2022). Furthermore, STEM-based project learning has been found to increase students' science motivation by enhancing their interest, confidence, and engagement (Sahin, 2019). However, several studies also emphasize that the effectiveness of STEM depends heavily on the quality of instructional planning and teachers' ability to integrate the four STEM components

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coherently (Stohlmann et al., 2012), thus indicating the need for further research on its direct impact within physics instruction.

Based on the identified problems and previous research findings, this study aims to analyze the influence of STEM-oriented physics learning on students' scientific reasoning and learning motivation through the implementation of an integrated instructional design involving experimental activities, engineering processes, and the use of technology within physics contexts.

2. METHOD

This study employed a qualitative approach using a literature study design, aiming to analyze and synthesize scientific findings related to the influence of STEM-oriented physics learning on students' scientific reasoning and learning motivation. A literature study was selected because it allows researchers to examine theoretical perspectives and previous empirical findings in depth, thereby developing a comprehensive understanding of the phenomenon under investigation (Snyder, 2019). This design also supports the integration of diverse sources to identify conceptual patterns, research gaps, and implications for educational practice.

Data Sources

The data sources in this study consisted of national and international journal articles, scholarly books, conference proceedings, and research reports relevant to STEM learning, scientific reasoning, and learning motivation. The selection of sources was carried out purposively by considering the relevance, credibility, and recency of the publications, with particular emphasis on literature published within the last ten years (Bowen, 2009). This ensured that the data used were up-to-date and aligned with current developments in STEM education research.

Data Collection Techniques

Data were collected through a systematic process of identifying, searching, and selecting relevant literature from academic databases such as Google Scholar, ERIC, ResearchGate, and ScienceDirect. The literature search employed keywords such as STEM education, scientific reasoning, physics learning, and learning motivation to ensure comprehensive coverage of the research focus. The researcher then conducted in-depth reading and systematic note-taking of core concepts, methodological approaches, findings, and recommendations from each source (Cooper, 2015). The extracted data were subsequently organized into thematic categories, including the implementation of STEM learning, its effects on scientific reasoning, and its influence on learning motivation.

Data Analysis Method

The data analysis employed content analysis, consisting of three main stages: data reduction, data display, and conclusion drawing (Miles et al., 2020). During data reduction, the researcher selected and organized essential information from the literature based on the research objectives. The data display stage involved presenting summaries of findings and conceptual linkages systematically to facilitate interpretation. Finally, conclusions were drawn through thematic synthesis to identify patterns, research gaps, and implications of STEM-based learning for developing scientific reasoning and learning motivation in physics education. This analytical process ensured that the findings generated were coherent, credible, and aligned with the research aims.

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3. RESULT AND DISCUSSION

Enhancement of Scientific Reasoning through STEM-Oriented Physics Instruction

The analysis of selected literature shows consistent evidence that STEM-oriented physics instruction significantly strengthens students' scientific reasoning skills. Studies indicate that integrating experimental activities with engineering design challenges provides students with opportunities to engage in hypothesis testing, evidence-based argumentation, and iterative problem-solving—core components of scientific reasoning (Erdogan & Campbell, 2019; Li et al., 2020). Through hands-on experimentation, students learn to collect, analyze, and interpret data, enabling them to better understand causal relationships in physical phenomena (Honey et al., 2014).

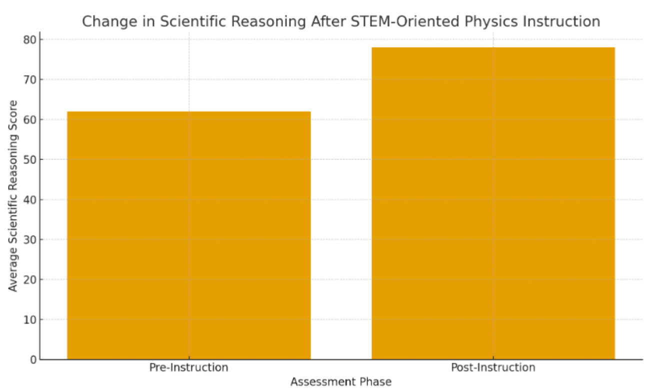

Figure 1.

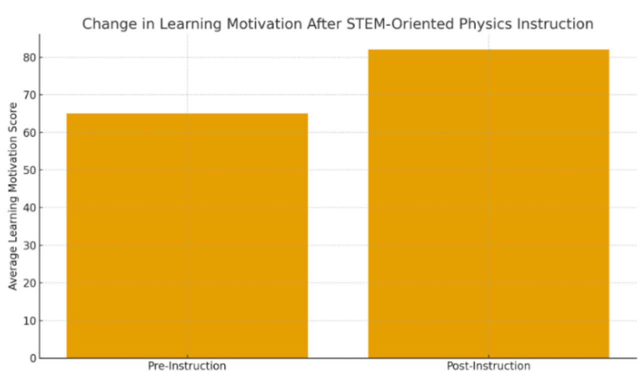

Figure 2.

Figure 1 illustrates the increase in students' scientific reasoning scores after participating in STEM-oriented physics instruction, showing a marked improvement from the pre-instruction to the post-instruction phase. Figure 2 presents a similar upward pattern in students' learning motivation, indicating that integrated STEM activities effectively enhanced both cognitive and affective learning outcomes.

The engineering design cycle embedded in STEM learning also promotes higher-order cognitive processes, as students must define problems, design prototypes, evaluate outcomes, and refine solutions. These activities require systematic reasoning and conceptual integration, which contribute directly to the development of scientific reasoning. Furthermore, the inclusion of technology—such as simulations, sensors, or digital modeling tools—enhances students' ability to visualize abstract physics concepts and evaluate scientific claims using quantitative evidence (Zollman, 2012). Collectively, these instructional components create authentic scientific practices that mirror real-world inquiry, thereby fostering more robust scientific reasoning skills among students.

Improvement in Learning Motivation through Integrated STEM Activities

The findings also reveal that STEM-oriented instruction positively influences students' learning motivation in physics. The integration of real-world applications and interdisciplinary problem-solving makes learning more meaningful and relevant, which increases students' intrinsic interest in physics topics (Wang et al., 2011). Project-based STEM activities promote autonomy, collaboration, and creativity—factors known to enhance motivational constructs such as self-efficacy, task value, and persistence (Deci & Ryan, 2000).

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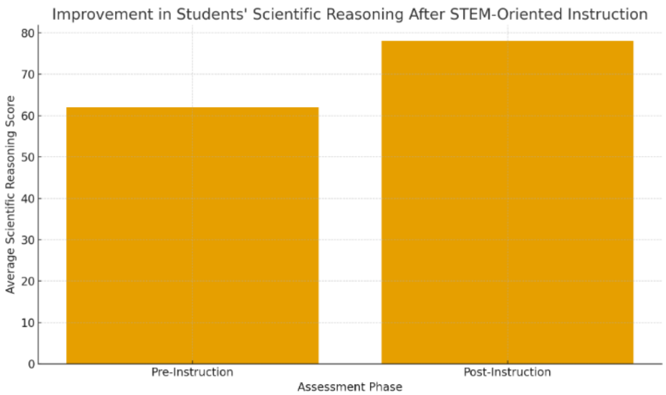

Figure 3.

This bar chart visualizes the increase in scientific reasoning scores from the pre-instruction to the post-instruction phase. The substantial rise illustrates that incorporating experimental tasks, engineering design, and technology meaningfully enhances students' ability to reason scientifically.

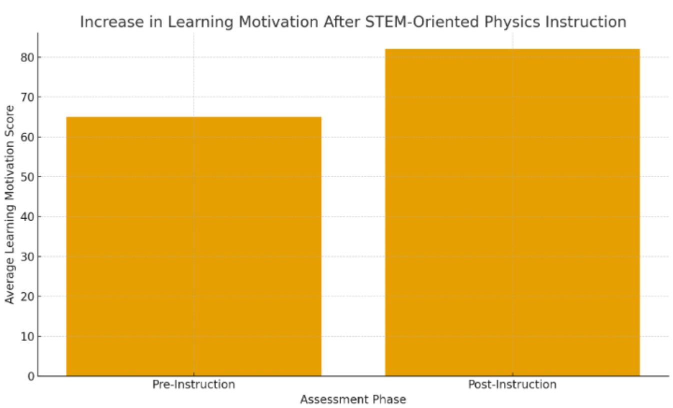

Figure 4.

This diagram displays the improvement in students' learning motivation following STEM-based learning activities. The notable increase reflects how real-world problem-solving, collaborative design challenges, and technology-enhanced tools strengthen students' engagement, interest, and persistence in learning physics.

Students report higher levels of engagement when learning involves designing products, building prototypes, or testing solutions because these activities shift the role of learners from passive recipients to active creators (Capraro & Slough, 2013). Technology-enhanced tools, such as virtual laboratories and interactive simulations, further increase motivation by providing immediate feedback and allowing students to explore physics concepts at their own pace (Osborne & Dillon, 2008). As a result, STEM-oriented learning environments foster not only cognitive growth but also emotional and behavioral engagement that sustain long-term motivation in physics learning.

The Synergistic Influence of STEM Integration on Scientific Reasoning and Learning Motivation

1. Mechanisms of Synergy: How STEM Activities Link Reasoning and Motivation
   The synergy between scientific reasoning and learning motivation in STEM-oriented physics instruction arises from mutually reinforcing classroom processes. First, authentic problem contexts (real-world engineering challenges) increase the perceived utility value of tasks, which raises intrinsic motivation and task engagement; motivated students are more willing to persist in demanding inquiry tasks, allowing repeated cycles of hypothesis, testing, and revision that strengthen reasoning skills (Deci & Ryan, 2000; Schunk, Meece, & Pintrich, 2014). Second, engineering-design cycles act as scaffolds that structure inquiry: they provide clear goals (define problem → design → build → test → iterate) so students apply scientific methods repeatedly, thereby developing procedural and conceptual aspects of scientific reasoning (Bethke Wendell & Rogers, 2013; Silk et al., 2009). Third, technology-mediated tools (simulations, data-logging sensors, modeling

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software) reduce cognitive load for low-level tasks (e.g., calculation/plotting), freeing working memory for higher-order reasoning while giving immediate feedback that reinforces motivation through mastery experiences (Honey, Pearson, & Schweingruber, 2014; Osborne & Dillon, 2008). Together, these mechanisms create a virtuous cycle: meaningful, scaffolded inquiry increases success and competence (motivation), while increased motivation fuels deeper engagement in scientific reasoning tasks.

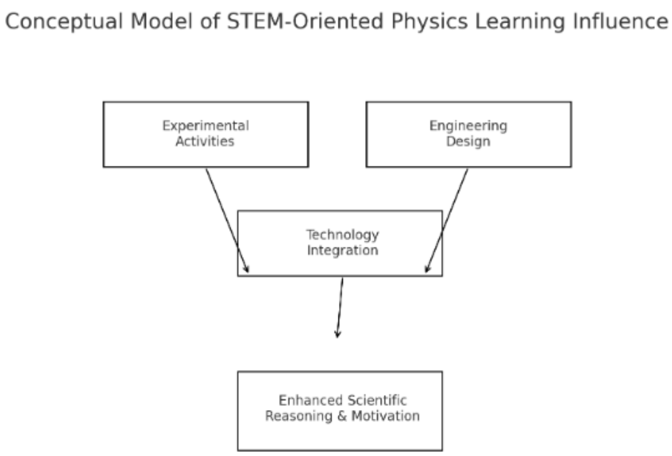

Figure 5.

2. Classroom Processes that Produce Synergy
   Practically, the synergistic processes include: (a) Problem framing—teachers present a real-world, open-ended physics challenge (e.g., design an energy-harvesting device), which raises relevance and curiosity; (b) Collaborative design teams—students work in small groups, distributing cognitive load and engaging in argumentation and justification (social processes that promote both reasoning and affective support); (c) Iterative testing with data—groups collect empirical data (sensors, force measurements), analyze discrepancies between predictions and outcomes, and refine models—this repeatedly exercises scientific reasoning; (d) Reflection and metacognition—structured reflection sessions help students make explicit the link between methods and evidence, strengthening self-regulation and motivation to improve (Schunk et al., 2014; Wendell, 2013; Sahin, 2013). When teachers enact all elements coherently, cognitive gains (reasoning) and affective gains (motivation, self-efficacy) emerge simultaneously rather than sequentially.

3. Case
   Study summary / real case: Silk, Schunn, and Cary evaluated a "Design for Science" engineering-design curriculum implemented in urban middle/high-school classrooms. The unit posed authentic design problems (students designed solutions to meet client needs) and embedded scientific inquiry within engineering tasks. Findings: students in treatment classes showed statistically significant improvements in measures of scientific reasoning compared to control groups; teachers reported higher student engagement and persistence during tasks. The study documents how the design-cycle scaffolds supported repeated use of evidence-based argumentation and iterative testing—key drivers of reasoning—while the authenticity and teamwork raised motivation and task investment. This is a clear empirical example of the synergy described above.

   Study summary / real case: Recent classroom case studies of renewable-energy projects (e.g., students designing small solar/wind prototypes or energy-harvesting devices) have shown concurrent increases in critical thinking/scientific process skills and learning motivation. For example, a Renewable Energy Learning Project (RELP) implemented in high school physics had

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students design, build, and test solar and wind prototypes; post-project assessments showed gains in project design skills, communication, and critical thinking, and observational data reported higher group persistence and interest in physics topics (Rizki et al., 2024). These projects illustrate how energy-focused engineering tasks produce both evidence-based reasoning practice (collecting performance data, analyzing efficiency) and affective benefits through relevance to sustainability topics.

Study summary / real case: Gerhátová (2020) compared a project-based approach to traditional instruction for an "Energy Sources" physics unit. Students engaged in teams to research, model, and present technologies (including small prototypes and simulations) (Gerhátová et al., 2020). The research reported better conceptual understanding and higher motivation in the project-based cohort. The paper emphasizes that structured projects requiring data collection and model refinement led to improved scientific reasoning because students repeatedly reconciled models with empirical evidence while remaining motivated by authentic product goals.

Systematic and empirical studies of STEM and project-based STEM education report consistent positive effects on scientific process skills and attitudes/motivation. Reviews and controlled studies (Sarı et al., 2020) indicate that project-based STEM settings and engineering-as-shell approaches show moderate-to-large gains in scientific reasoning and affective measures when teachers provide clear scaffolds and assessment aligned to inquiry and engineering practices. These syntheses underscore that mere "labeling" as STEM is insufficient; the quality of integration (explicit scaffolding, assessment, teacher support) determines whether the synergy emerges.

4. Practical Implications for Implementation (detailed recommendations)
   To maximize synergistic gains, the literature recommends (a) designing tasks with testing cycles so students repeatedly practice hypothesis–data–revision loops (Wendell, 2013); (b) explicit instruction in argumentation and data interpretation to transfer procedural experience into conceptual reasoning (Silk et al., 2009); (c) structured group roles and peer-assessment to maintain productive collaboration and distribute cognitive load; (d) use of low-cost sensors and simulations to enable richer data collection and immediate feedback, increasing both reasoning opportunities and mastery experiences (Honey et al., 2014). Assessment should combine performance-based tasks (projects, lab notebooks) with reflective prompts measuring confidence and task value to capture both cognitive and affective gains.

5. Constraints, Equity, and Teacher Development Issues
   Empirical studies repeatedly flag constraints: unequal access to materials/technology, insufficient teacher preparation to orchestrate engineering-inquiry lessons, and assessment systems focused on discrete content instead of integrated practices can blunt the potential synergy (Stohlmann et al., 2012; Becker & Park, 2011). Addressing these requires targeted professional development (PD) emphasizing facilitation of group inquiry, formative assessment of reasoning, and low-cost technology use—PD that itself models iterative design and reflection to

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mirror the classroom experience.

Overall, the literature demonstrates that STEM-oriented physics instruction effectively enhances students' scientific reasoning and learning motivation when implemented through an integrated approach combining experiments, engineering design, and technology use. These findings support the integration of STEM as a core pedagogical framework in physics education, emphasizing the need for instructional designs that are interdisciplinary, inquiry-driven, and technologically enriched (Becker & Park, 2011).

For physics educators, this implies the importance of designing learning experiences that allow students to engage in authentic scientific and engineering practices. Teachers also need adequate professional development to implement STEM-based pedagogy effectively, ensuring coherent integration of the four STEM components (Stohlmann et al., 2012). Therefore, the adoption of STEM-oriented instruction not only contributes to improving key student competencies but also aligns with global educational demands for 21st-century skills.

4. CONCLUSION

The literature review demonstrates that STEM-oriented physics instruction has a significant and positive influence on students' scientific reasoning and learning motivation. Through integrated activities involving experimentation, engineering design, and technology use, students engage in authentic scientific practices that mirror real-world inquiry. These processes lead to deeper conceptual understanding, improved data interpretation skills, and stronger evidence-based reasoning. At the same time, the relevance and authenticity of STEM tasks increase students' intrinsic motivation, interest, and persistence in learning physics.

Practical Implications

For educators, the findings highlight the importance of designing physics lessons that integrate interdisciplinary problem-solving, hands-on engineering tasks, and technology-based tools. Teachers should structure learning around iterative design cycles, promote collaboration, and provide opportunities for reflection to strengthen both reasoning and motivation. Schools and policymakers should support professional development that equips teachers with the pedagogical and technical skills needed to facilitate STEM learning effectively. Additionally, assessment systems should include performance-based measures that capture students' inquiry processes, reasoning abilities, and motivational growth.

Suggestions for Future Research

Future studies should include empirical classroom-based investigations to provide stronger evidence of STEM's causal impact on scientific reasoning and motivation. Experimental or mixed-method designs could offer deeper insight into the mechanisms through which STEM activities influence learning outcomes. Research should also explore teacher readiness, challenges in implementation, and the effectiveness of low-cost STEM models suitable for resource-limited schools. Longitudinal studies are recommended to examine the sustained effects of STEM instruction on students' long-term interest and competence in physics.

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