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RESEARCH ARTICLE

Innovative Science Project Instruction via Design Thinking: A Multidisciplinary Integration towards STEAM Education

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Abstract

Education in the 21st century emphasizes the development of future-ready competencies over rote memorization, particularly critical thinking, collaboration, and creative problem-solving. However, science project instruction at the lower secondary level frequently encounters challenges; learners often lack the capacity to integrate interdisciplinary knowledge within the STEAM framework and struggle to apply scientific and engineering principles to construct functional prototypes that address authentic real-world problems.

Consequently, this academic article aims to propose a comprehensive pedagogical framework that synergistically integrates Design Thinking, Project-Based Learning (PjBL), Problem-Based Learning (PBL), and Active Learning within a STEAM education context. This instructional innovation is operationalized through five iterative stages: Empathize, Define, Ideate, Prototype, and Test. To elucidate the practical implementation of this instructional model, the article presents the design of pedagogical tools and systematic worksheets that guide learners through each phase.

The study highlights that this multidisciplinary approach not only empowers students to create science projects that solve real-life problems, but also discusses the theoretical implications and pedagogical benefits focused on cultivating essential future skills. Ultimately, this article serves as a practical framework that educators can adapt to effectively elevate science instruction.

Keywords: Design thinking, Project-based learning, Active learning, STEAM education, Science project

Introduction

Education in the 21st century emphasizes the development of future-ready competencies over traditional rote memorization, prioritizing essential skills such as critical thinking, collaboration, and creative problem-solving (Guaman-Quintanilla et al., 2023; Lin et al., 2025). To navigate complex global challenges, active learning has emerged as a paramount pedagogical paradigm. Active learning, grounded in constructivist theory, positions students as dynamic participants who construct knowledge through engagement and reflection rather than passive reception (Doolittle et al., 2023; Pande & Bharathi, 2020). Within this context, science instruction serves as a critical mechanism for experiential learning; however, laboratory and project-based instruction often fail to generate desired outcomes due to a low level of inquiry, where students simply follow instructions without student agency or authentic problem-solving processes (Zhu et al., 2024). Consequently, learners frequently struggle to establish cohesive connections between their scientific knowledge and authentic real-world problems.

To operationalize active learning and address these instructional gaps, Project-Based Learning (PjBL) and Problem-Based Learning (PBL) are frequently employed. PjBL engages learners in knowledge construction by having them accomplish meaningful projects and develop real-world artifacts (Guo et al., 2020). Conversely, PBL immerses learners in ill-

defined, open-ended scenarios that demand critical analysis, collaborative discussion, and evidence-based reasoning (Liu & Pásztor, 2022). While both approaches have proven efficacy in enhancing students' academic achievement and motivation, students often require a structured cognitive scaffold to navigate the creative and iterative processes required for true innovation (Henriksen et al., 2017).

Design Thinking (DT) provides this critical architecture. As a human-centered, iterative methodology, DT empowers students to transition from passive learners to empowered creators (Lin et al., 2025). The DT process typically comprises five distinct stages: Empathize, Define, Ideate, Prototype, and Test (Lin et al., 2025). By integrating DT as the core pedagogical backbone, the instructional model synergizes the investigative nature of PBL and the artifact-driven focus of PjBL, providing a systematic framework that allows learners to present more innovative solutions (Nordin et al., 2024). Furthermore, DT operationalizes active learning while fostering empathy, ensuring that students design solutions that are deeply connected to authentic human needs (Henriksen et al., 2017).

Consequently, this academic article aims to propose a comprehensive pedagogical framework that synergistically integrates Design Thinking, Project-Based Learning, Problem-Based Learning, and Active Learning within a STEAM education context. By elucidating this multidisciplinary instructional model, this paper seeks to provide educators with a replicable and practical strategy to elevate science project instruction. Specifically, the objectives of this review article are threefold:

1. To propose a comprehensive pedagogical framework that synergistically integrates Design Thinking, Project-Based Learning (PjBL), Problem-Based Learning (PBL), and Active Learning within a STEAM education context.

2. To elucidate the practical implementation of this integrated model in lower secondary science education, specifically through the design of stage-guided instructional tools and canvas-based worksheets.

3. To discuss the theoretical implications and pedagogical benefits of this multidisciplinary approach in cultivating students' 21st-century skills, including critical thinking, collaboration, and creative problem-solving.

Context and review of literature

Design thinking

Modern pedagogy increasingly prioritizes higher-order thinking, creativity, and authentic problem-solving over traditional rote memorization. As science education shifts toward learner-centered models, specific instructional frameworks have become essential for fostering meaningful learning. Design Thinking (DT) is widely recognized as a human-centered approach to innovation and problem-solving (Razzouk & Shute, 2012). Originally rooted in design fields, DT has been extensively adapted across various disciplines to address complex, ill-defined, or "wicked" problems that have no straightforward solutions (Buchanan, 1992, as cited in Pande & Bharathi, 2020). The methodology fundamentally blends analytical reasoning with intuitive, divergent thinking to generate novel ideas and effective solutions (Razzouk & Shute, 2012). The DT process typically operationalizes this approach through five iterative stages: Empathize, Define, Ideate, Prototype, and Test (Crites & Rye, 2020; Pande & Bharathi, 2020).

In educational settings, DT is deeply anchored in constructivist learning theory, which posits that learners construct knowledge through active engagement and experiential practices rather than passive reception (Pande & Bharathi, 2020). By integrating DT into the classroom, educators can transform students from passive learners into empowered creators and active problem-solvers (Lin et al., 2025).

The integration of DT into the current study's instructional framework is highly imperative to bridge the gaps in traditional active learning strategies. While Project-Based Learning (PjBL) engages learners in knowledge construction by having them accomplish meaningful projects and develop real-world artifacts (Guo et al., 2020), and Problem-Based Learning (PBL) immerses learners in open-ended scenarios that demand critical analysis (Liu & Pásztor, 2022), students often require a structured cognitive scaffold to navigate the creative and iterative processes necessary for true innovation (Henriksen et al., 2017). DT provides this essential architecture.

By incorporating the empathize phase, DT enables learners to view scientific challenges from a deeper, human-centric perspective, leading them to understand who the stakeholders are and what their actual needs are (Crites & Rye, 2020; McCurdy et al., 2020). Furthermore, within a STEAM education context, DT serves as the pedagogical backbone that synergizes the investigative nature of PBL with the artifact-driven focus of PjBL. This multidisciplinary integration ensures that secondary students are not merely acquiring theoretical knowledge, but are effectively guided to apply scientific and engineering principles to construct functional prototypes that address authentic, real-world problems (Romero Caballero et al., 2024).

Project-based learning

Project- based learning (PjBL) is widely recognized as an inquiry-based instructional method that engages learners in knowledge construction by having them accomplish meaningful projects and develop real-world products (Guo et al., 2020). A key hallmark that distinguishes PjBL from other student-centered pedagogies is its explicit emphasis on the creation of tangible artifacts to solve authentic problems (Guo et al., 2020). By providing students with opportunities to participate in real problem- solving, PjBL bridges the gap between theoretical disciplinary knowledge and practical application in authentic professional contexts (Guo et al., 2020).

In the landscape of modern science education, integrating PjBL is considered a highly effective approach to providing students with both cognitive knowledge and professional soft skills, such as critical thinking, problem- solving, and teamwork (Guo et al., 2020). When implemented within a STEAM education framework, this interdisciplinary approach empowers students to apply their knowledge from different perspectives to generate a solution to a complex problem (Aguilera & Ortiz-Revilla, 2021).

However, the successful implementation of educational innovations requires learners to navigate complex and ill-defined problems, which often demands a structured cognitive architecture (Pande & Bharathi, 2020). While PjBL focuses on the final product, the integration of Design Thinking (DT) provides the necessary methodological scaffold for students throughout the creative process (Lin et al., 2025). By blending analytical reasoning with intuitive thinking to generate novel ideas, DT helps students deeply understand user needs and continuously refine their solutions (Pande & Bharathi, 2020). Consequently, synergizing DT with PjBL ensures that secondary students are not merely acquiring theoretical knowledge, but are systematically guided to construct functional prototypes that address authentic human needs (Guo et al., 2020; Lin et al., 2025)

Problem-based learning

Problem- based learning (PBL) is widely acknowledged as a dynamic, learner-centered instructional approach that immerses students in complex, open- ended, and real- world problems to stimulate active knowledge construction (Gumisirizah et al., 2023; Liu & Pásztor, 2022). Unlike traditional pedagogical methods that rely on passive information reception, PBL requires learners to work collaboratively to identify knowledge gaps, analyze data, and formulate viable solutions through evidence-based reasoning (Ali, 2019; Gumisirizah et al., 2023). By engaging students in authentic learning situations, this approach has proven highly effective in cultivating essential twenty-first- century competencies, particularly critical thinking, complex problem- solving, and self- directed learning skills (Nordin et al., 2024).

Within the context of science and STEAM education, PBL serves as a crucial mechanism to bridge the gap between theoretical concepts and practical applications. When students are confronted with ill-structured scenarios, they are compelled to integrate multidisciplinary knowledge to develop systematic solutions (Liu & Pásztor, 2022). Consequently, PBL significantly enhances academic achievement and learning motivation by allowing students to perceive the practical relevance of scientific principles in addressing authentic global and community challenges (Cook & Bush, 2018; McCurdy et al., 2020).

However, while PBL provides a robust foundation for developing analytical and problem- solving skills, students often encounter difficulties in translating their conceptual solutions into tangible, innovative artifacts that genuinely reflect human needs. To maximize the efficacy of PBL, it is imperative to integrate DT as a complementary pedagogical architecture (McCurdy et al., 2020; Nordin et al., 2024). The incorporation of DT

specifically addresses the dimensions of creativity and human-centric understanding that traditional PBL frameworks may not sufficiently emphasize (Guaman-Quintanilla et al., 2023). By embedding the empathy and prototyping phases of DT into the PBL environment, students are guided to deeply understand the stakeholders involved, view scientific challenges from a broader perspective, and iteratively test their ideas (McCurdy et al., 2020). Therefore, the synergy between PBL and DT within a STEAM framework ensures that learners not only systematically analyze problems but also successfully design and construct practical, empathetic, and innovative prototypes.

Active learning

Active learning is widely recognized as a student-centered pedagogical paradigm that advocates for a fundamental shift from traditional, instructor-centered lecture formats to dynamic environments where learners take responsibility for their own educational processes (Liu et al., 2024; Ting et al., 2023). Operationally, active learning encompasses instructional methodologies that engage students in meaningful activities and reflection, ensuring they are not merely passive recipients of information but active participants in their learning journey (Doolittle et al., 2023). By prioritizing student participation and engagement, this approach effectively addresses the limitations of didactic instruction and aligns with the demands of contemporary education to cultivate self-directed learners who are capable of navigating complex modern challenges (Ting et al., 2022).

Grounded deeply in constructivist learning theory, active learning posits that individuals optimally construct their own knowledge through direct experience, social interaction, and continuous cognitive reflection (Doolittle et al., 2023; Pande & Bharathi, 2020). Within the context of science and STEM education, implementing active learning strategies is specifically targeted at reinforcing higher-order cognitive skills, including critical analysis, complex problem-solving, and creative evaluation (Ting et al., 2022). Furthermore, researchers indicate that when students are situated at the center of the learning environment, they demonstrate heightened curiosity, emotional engagement, and the capacity for deep, transformative learning that fundamentally changes their perception of the world and develops new representations of knowledge (Doolittle et al., 2023; Liu et al., 2024).

To operationalize active learning effectively in secondary science classrooms, educators frequently deploy PBL and PjBL to engage students in authentic, real-world challenges (Nordin et al., 2024). However, establishing a comprehensive active learning environment requires a structured methodological scaffold to guide students through complex problem-solving and innovation processes. DT inherently functions as a systematic architecture that facilitates active learning by empowering students to empathetically observe user needs, collaboratively ideate, and iteratively prototype tangible solutions (Baričević & Luić, 2023). Consequently, integrating DT with PBL and PjBL cultivates an advanced active learning ecosystem where students are systematically guided to transform theoretical scientific knowledge into innovative artifacts, thereby fulfilling the ultimate educational objectives of twenty-first-century learning.

STEAM education

In the contemporary educational landscape, STEAM education, an acronym encompassing Science, Technology, Engineering, Arts, and Mathematics, has emerged as a transformative pedagogical paradigm designed to cultivate innovation and practical problem-solving capabilities (Conradty & Bogner, 2020; Zhang & Jia, 2024). Expanding upon the traditional STEM framework, the deliberate inclusion of the arts serves a profound purpose by unifying convergent analytical reasoning with divergent creative thinking (Aguilera & Ortiz-Revilla, 2021; Souliotou, 2016). This interdisciplinary integration allows learners to transcend traditional disciplinary boundaries, enabling them to explore complex phenomena through a holistic perspective rather than acquiring knowledge in isolated fragments (Cook & Bush, 2018). Consequently, STEAM education is widely recognized as a critical mechanism for equipping students with essential twenty-first-century competencies, empowering them to effectively navigate and address the multifaceted challenges of a rapidly evolving global society (Lin et al., 2025).

To effectively operationalize STEAM education within secondary science classrooms, educators must

move beyond didactic instruction and establish robust active learning environments. Instructional methodologies such as project-based learning (PjBL) and problem-based learning (PBL) are fundamentally aligned with the objectives of STEAM education, as they immerse students in authentic, real-world scenarios that demand multidisciplinary knowledge application (Guaman-Quintanilla et al., 2023; Nordin et al., 2024). While PBL challenges learners to investigate ill-structured problems through evidence-based reasoning, PjBL drives them to translate their conceptual understanding into tangible, functional artifacts (Guo et al., 2020; Liu & Pásztor, 2022). By integrating these active learning strategies within a STEAM context, students are intrinsically motivated to assume ownership of their educational process and transform theoretical scientific principles into practical applications.

However, maximizing the efficacy of this multidisciplinary integration requires a systematic architecture to guide learners through the complexities of innovation. Design Thinking (DT) functions as this essential cognitive scaffold (Henriksen et al., 2017). By embedding the empathetic, ideational, and prototyping phases of DT into the STEAM-driven PjBL and PBL environments, educators can ensure that students are not merely assembling projects mechanically, but are deeply engaged in human-centered problem solving (McCurdy et al., 2020). The synergy among STEAM education, active learning methodologies, and Design Thinking ultimately establishes a comprehensive pedagogical framework. This synthesized approach guarantees that students systematically apply scientific and engineering principles alongside artistic creativity to construct innovative prototypes that genuinely address authentic human needs, thereby fulfilling the ultimate goals of modern science education (Lin et al., 2025; Zhang & Jia, 2024).

Method

This review article employs a conceptual synthesis methodology to construct a multidisciplinary pedagogical framework for science project instruction. The development of the proposed instructional innovation was conducted through three systematic phases: theoretical review and gap identification, pedagogical integration and mapping, and framework operationalization.

Theoretical review and gap identification

An extensive review of existing literature was initially conducted to explore the current landscape of science project instruction within the STEAM education context. The review focused on identifying the pedagogical limitations of traditional active learning strategies, specifically PjBL and PBL (Guo et al., 2020; Liu & Pásztor, 2022). The analysis revealed a critical need for a structured cognitive scaffold to guide secondary students through the complex and iterative processes of innovation and human-centered problem-solving.

Pedagogical integration and mapping

To address the identified instructional gaps, this study adopted an integrative approach to theory and practice. Drawing inspiration from previous research that mapped constructivist learning tenets to DT processes (Pande & Bharathi, 2020), the present study systematically mapped the investigative nature of PBL and the artifact-driven focus of PjBL onto the five-stage architecture of DT. The integration process ensured that the five stages of DT, namely Empathize, Define, Ideate, Prototype, and Test, were synergistically paired with the most appropriate active learning strategies. This mapping was designed to maximize student engagement and cognitive development (Crites & Rye, 2020; Nordin et al., 2024).

Framework operationalization

In the final phase, the synthesized theoretical concepts were translated into practical instructional guidelines. To elucidate the practical implementation of this integrated model for lower secondary science education, the conceptual framework was operationalized through the design of stage-guided pedagogical tools and canvas-based worksheets. These tools were structured to provide educators with a replicable strategy. Consequently, this approach seamlessly transforms abstract multidisciplinary theories into actionable classroom practices.

Findings

To successfully operationalize the proposed instructional innovation, it is crucial to systematically delineate the specific student activities and the corresponding pedagogical shifts required of educators

throughout the design process. As illustrated in Figure 1, the proposed multidisciplinary pedagogical framework is executed through five specific phases.

Phase 1: Empathize (PBL and Active Learning)

Student activities

The instructional process commences with Problem-Based Learning (PBL) and Active Learning strategies, requiring students to utilize an "Empathy Map" worksheet to deeply explore authentic challenges. In this phase, learners investigate three interconnected dimensions: the self- dimension regarding personal interests, the target user dimension involving direct interviews to gather meaningful insights, and the societal dimension addressing contemporary societal trends. Empathy is widely recognized as a key component of human- centered innovation, enabling students to deeply understand and connect with the actual experiences and needs of users (Goldman & Zielezinski, 2016). By working in collaborative groups to conduct field interviews, students are guided to move beyond mere assumptions and systematically identify three to five genuine problems faced by their target stakeholders.

Teacher as a facilitator

Since the learner is situated at the center of the constructivist teaching and learning process, educators must transition from traditional instructors to learning facilitators (Noweski et al., 2012; Pande & Bharathi, 2020). In this initial phase, the facilitator's primary role is to guide students in formulating appropriate interview questions tailored to their target users and to provide continuous, constructive feedback during group discussions. Furthermore, the teacher connects this empathetic exploration to formal academic requirements by instructing students on how to synthesize these collected insights to construct the "Background and Significance" section of their science project report. This pedagogical scaffolding ensures that learners systematically bridge authentic user needs with formal scientific inquiry.

Phase 2: Define (PBL)

Student activities

Building upon the empathetic insights gathered in the initial stage, students transition into rigorous Problem-Based Learning to critically analyze the collected data. During this phase, learner groups engage in collaborative discussions to evaluate and select a single, highly specific problem to investigate. To ensure the viability of the project, the chosen issue must satisfy three fundamental criteria: it must align with the students' personal interests, address the authentic challenges of the target stakeholders, and demonstrate a potential positive societal impact. Subsequently, learners utilize the "Problem Statement" worksheet to systematically articulate the issue. This task requires them to explicitly outline four critical components including the core problem, its potential underlying causes, the stakeholders directly affected, and the overall significance of the problem. This systematic approach compels learners to work collaboratively to identify knowledge gaps and analyze data, which are essential processes in cultivating complex problem-solving and critical thinking skills (Gumisirizah et al., 2023).

Teacher as a facilitator

Within this phase, the educator continues to operate as a learning facilitator rather than a traditional knowledge transmitter. The primary pedagogical responsibility involves guiding students to refine their selected problem, ensuring that the issue is highly specific and explicitly grounded in relevant scientific and STEAM concepts. Furthermore, the facilitator provides structured guidance on how to systematically access and retrieve credible information from diverse academic sources. This explicit instruction empowers students to substantiate the significance of their research topic and effectively synthesize the literature required to construct the Literature Review section of their formal science project report. By providing this cognitive scaffolding, the teacher ensures that students seamlessly bridge their authentic problem identification with rigorous academic research protocols.

Phase 3: Ideate (PjBL and active learning)

Student activities

During the ideation phase, the instructional focus shifts from problem identification to the generation of creative solutions. Guided by Project-Based Learning and active learning principles, student groups participate in collaborative brainstorming sessions to produce a

diverse array of potential ideas. To manage this divergent thinking process systematically, learners utilize the "Idea Selection" worksheet. After generating multiple concepts, students apply convergent thinking to critically evaluate their ideas against three specific predefined criteria: project interest, practical feasibility, and the depth of STEAM integration. Ultimately, the groups score and prioritize their concepts to select the single most viable solution for further development. Engaging in this structured brainstorming and selection process empowers students to synthesize interdisciplinary knowledge and fosters both creative and critical thinking skills. Furthermore, the iterative cycle of generating extensive options and subsequently narrowing them down through systematic evaluation is essential for navigating complex problem- solving scenarios and arriving at innovative outcomes.

Teacher as a facilitator

In this phase, the educator's role is critical in cultivating an open and supportive active learning environment that encourages intellectual risk taking and unbounded creativity. The facilitator guides the brainstorming sessions by prompting students to defer immediate judgment and explore unconventional solutions. Additionally, the teacher provides essential pedagogical scaffolding during the idea evaluation process, ensuring that learners rigorously apply the selection criteria rather than relying on subjective preferences. By steering group discussions, the facilitator ensures that the selected solutions are not only practically feasible but also demonstrate a robust integration of science, technology, engineering, arts, and mathematics principles. This facilitation strategy effectively bridges imaginative exploration with the academic rigor required for subsequent project prototyping.

Phase 4: Prototype (PjBL)

Student activities

In the prototyping phase, the pedagogical focus shifts towards the materialization of abstract concepts. Guided by Project-Based Learning principles, students utilize the "Prototype Plan" worksheet to systematically outline the required materials, design conceptual models, and establish detailed operational procedures. This stage requires learners to translate their selected ideas into tangible artifacts that address the identified problem. Creating physical products to visualize solutions enables learners to represent their cognitive processes in a physical and collaborative manner. Furthermore, prototyping functions as a crucial mechanism that aids learners in generating more creative and innovative ideas while simultaneously synthesizing multidisciplinary STEAM knowledge. Through collaborative discourse around these physical objects, students effectively leverage their intuitive, experiential, and disciplinary knowledge to construct functional prototypes.

Teacher as a facilitator

During this phase, the educator assumes the role of an advisory coach who provides customized guidance tailored to the specific needs of each student group. The facilitator must allocate adequate instructional time for students to construct their prototypes and conduct preliminary data collection, ensuring that the learning environment supports active experimentation and continuous iteration. Additionally, the teacher provides essential pedagogical scaffolding by instructing students on how to systematically document their procedures to formulate the Methodology section of their formal science project report. By monitoring weekly progress presentations, the facilitator encourages students to embrace early failures as learning opportunities, which is vital for rapid improvement in the innovation process. This structured facilitation ensures that learners remain focused on their objectives while successfully bridging theoretical scientific principles with practical engineering applications.

Phase 5: Test (PjBL and active learning)

Student activities

In the final testing phase, learners transition to empirical evaluation by deploying their prototypes in authentic settings. Guided by Project-Based Learning and active learning principles, students utilize the "Test and Feedback" worksheet to systematically document their experimental results, challenges encountered, and constructive feedback from both instructors and target stakeholders. Testing allows developers to identify potential faults, gain valuable insights, and make necessary adjustments. Furthermore, design testing is widely recognized as a productive opportunity to fail,

learn, and improve rather than a summative judgment. Consequently, students actively engage in iterative refinement, utilizing the collected feedback to continuously modify their artifacts until the optimal solution that genuinely meets user demands is achieved. This iterative cycle ensures that the final science project is highly functional and deeply rooted in the actual needs of the community.

Teacher as a facilitator

During this evaluative stage, the educator continues to provide essential pedagogical scaffolding by instructing students on how to formally articulate their findings and synthesize the Results and Discussion sections of their final science project reports. To cultivate a comprehensive active learning environment, the facilitator orchestrates a "Science Pitching Day" event, which provides a formal platform for learners to publicly present their refined prototypes and articulate their design rationale. This public presentation process not only enhances students' communication skills but also allows the facilitator to comprehensively assess learning outcomes through structured rubrics. Ultimately, by establishing a supportive atmosphere that embraces iteration and constructive critique, the teacher empowers students to successfully complete their science projects while internalizing the complex problem- solving methodologies essential for innovation.

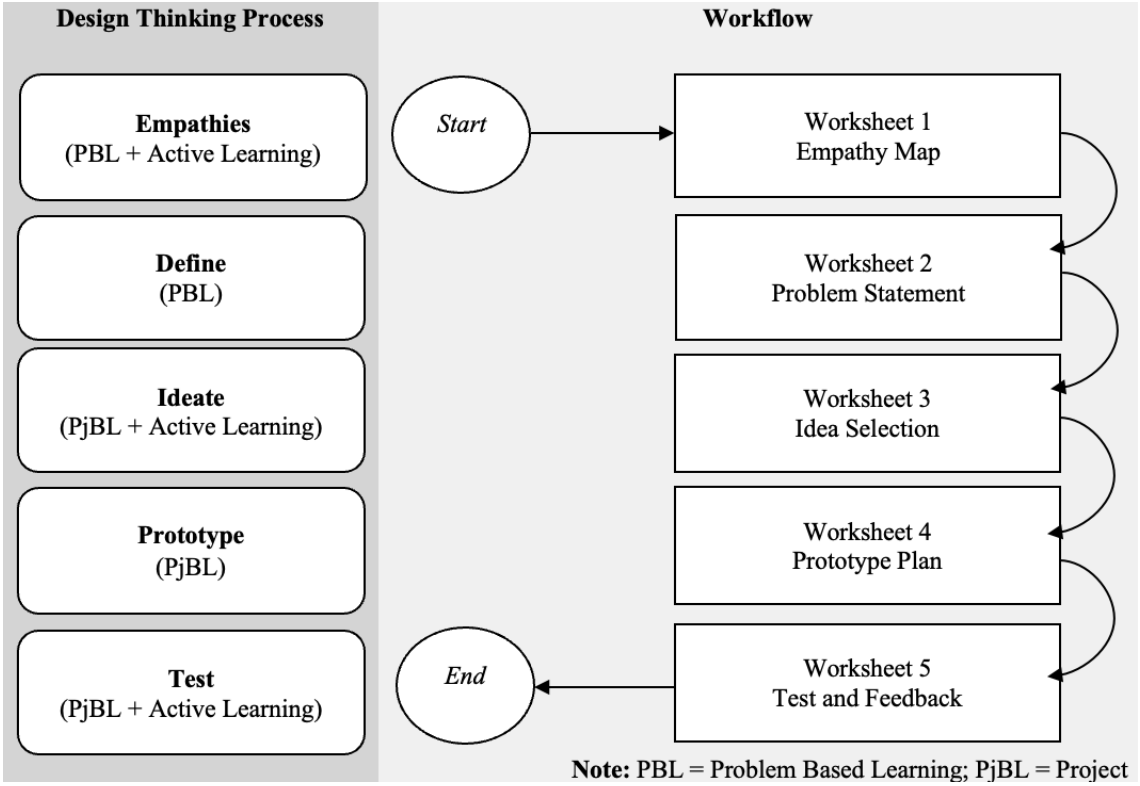

Figure 1 The proposed multidisciplinary pedagogical framework.
Source: Authors' original work.

Assessment and evaluation strategies

The successful implementation of this multidisciplinary instructional framework requires a fundamental paradigm shift in assessment methodologies. Traditional summative examinations are often insufficient for accurately measuring complex twenty- first- century skills, creative problem- solving, and practical artifact creation (Lin et al., 2025) . Therefore, a comprehensive, performance-based assessment approach is imperative to evaluate both the students' cognitive processes and their final tangible products (Guo et al., 2020).

To systematically assess student learning outcomes within this framework, educators must

employ a multidimensional evaluation rubric. In the proposed model, the assessment rubric is strictly structured across three core domains: Knowledge, Skills, and Attributes. The Knowledge domain evaluates the students' capacity to accurately integrate theoretical scientific principles and STEAM concepts into their project designs. The Skills domain assesses their procedural proficiency, specifically focusing on critical analysis, experimental execution, and interdisciplinary collaboration (Yüksel, 2025). Finally, the Attributes domain measures their intrinsic learning behaviors, including task responsibility, creative confidence, and communication effectiveness during the public presentation at the Science Pitching Day event. The utilization of comprehensive rubrics ensures that the evaluation of student artifacts remains objective, consistent, and directly aligned with the intended instructional objectives (Guo et al., 2020; Zhu et al., 2024).

Furthermore, formative assessment must be continuously integrated throughout the five iterative phases of the Design Thinking process. Facilitators are encouraged to evaluate students through their comprehensive self-reflection reports, which provide critical insights into their cognitive development, the practical challenges they encountered, and the dynamics of their peer collaboration (Zhu et al., 2024). By adopting this holistic assessment strategy, educators can accurately capture the multifaceted development of learners, thereby ensuring that the pedagogical innovation successfully cultivates both academic excellence and practical innovation skills.

Discussion

The proposed multidisciplinary pedagogical framework highlights a critical paradigm shift in secondary science education. By synergistically integrating DT, PjBL, PBL, and Active Learning within a STEAM context, this model addresses the limitations of traditional rote-memorization approaches (Guaman-Quintanilla et al., 2023). The integration of these methodologies fundamentally redefines the educator's instructional role, transitioning them from traditional knowledge transmitters to dynamic learning facilitators (Pande & Bharathi, 2020). This pedagogical shift empowers educators to provide the necessary cognitive scaffolding for students to navigate complex and ill-defined problems effectively (Henriksen et al., 2017).

A distinguishing feature of this framework is the centralization of empathy in the scientific inquiry process. While conventional PBL and PjBL effectively engage students in problem- solving and artifact creation, they often lack the explicit human-centric focus required for authentic innovation (McCurdy et al., 2020). The incorporation of the empathize phase compels students to deeply understand the actual experiences and needs of stakeholders (Crites & Rye, 2020). This empathetic connection not only enhances intrinsic motivation but also ensures that the resulting science projects are deeply rooted in addressing genuine community challenges. Consequently, this approach fosters a sense of global citizenship and social responsibility among learners (Henriksen et al., 2017; Lin et al., 2025).

Furthermore, the iterative nature of the five-phase model serves as a robust engine for cultivating essential 21st-century competencies. As students collaboratively brainstorm, evaluate ideas, and construct physical prototypes, they seamlessly blend analytical reasoning with divergent creative thinking (Pande & Bharathi, 2020). This active learning environment requires learners to synthesize multidisciplinary STEAM knowledge to materialize abstract concepts into functional solutions (Nordin et al., 2024). Consequently, students systematically develop critical thinking, creative confidence, and interdisciplinary collaboration skills, which are highly demanded in the modern workforce (Guo et al., 2020).

Finally, the successful operationalization of this framework necessitates a holistic approach to assessment. Traditional summative evaluations are insufficient for capturing the multifaceted development of learners in this context (Lin et al., 2025). The proposed multidimensional rubric, encompassing Knowledge, Skills, and Attributes, ensures that both the cognitive processes and the tangible artifacts are evaluated objectively (Guo et al., 2020; Zhu et al., 2024). By embracing this comprehensive pedagogical and assessment architecture, educators can effectively transform students into empowered creators who are ready to tackle the complex sociotechnical challenges of the future.

Conclusion

In conclusion, this article presents a comprehensive pedagogical framework that effectively integrates Design Thinking (DT), Project-Based Learning (PjBL), Problem-Based Learning (PBL), and Active Learning to elevate science project instruction within a STEAM education context. The synthesis of these methodologies systematically addresses the limitations of traditional, rote-memorization approaches by positioning students as active constructors of knowledge (Doolittle et al., 2023). While PBL initiates the learning process through rigorous investigation of authentic problems (Liu & Pásztor, 2022), and PjBL drives the materialization of solutions into tangible artifacts (Guo et al., 2020), DT serves as the essential cognitive scaffold (Henriksen et al., 2017). By employing the five iterative stages of DT, the proposed framework successfully bridges the gap between theoretical scientific principles and practical engineering applications, ensuring that secondary students develop innovations that genuinely address human needs (Guaman-Quintanilla et al., 2023).

The anticipated benefits of implementing this multidisciplinary instructional innovation extend significantly beyond foundational academic achievement. Engaging in this structured, human-centered problem-solving process empowers students to cultivate vital twenty- first-century competencies, particularly critical thinking, creative confidence, interdisciplinary collaboration, and empathetic reasoning (Lin et al., 2025). Furthermore, integrating Arts into the STEAM framework enhances students' divergent creative thinking, enabling them to visualize and construct prototypes with higher practical and aesthetic value (Zhang & Jia, 2024). Ultimately, this pedagogical synergy transforms learners from passive recipients of information into empowered creators who are capable of navigating complex global challenges (Doolittle et al., 2023).

To maximize the efficacy of this instructional model, several pedagogical recommendations must be considered. Foremost, educators must fundamentally shift their instructional paradigm from traditional knowledge transmitters to dynamic learning facilitators (Nordin et al., 2024; Yüksel, 2025). Teachers should provide continuous cognitive scaffolding, encourage intellectual risk- taking, and foster a classroom environment where early failures are embraced as productive learning opportunities for iterative refinement (Cutumisu et al., 2019). Additionally, institutional support is required to address practical constraints; educators must allocate adequate instructional time for the complex prototyping and testing phases, and ensure that students have access to appropriate technological tools and multidisciplinary resources (Nordin et al., 2024).

Regarding future applications, the proposed framework exhibits substantial potential for adaptability across diverse educational landscapes. While this study contextualizes the innovation within a lower secondary science project course, future implementations should explore its integration into other core academic disciplines, such as mathematics, social sciences, and humanities (Lin et al., 2025). Moreover, educational researchers and practitioners are encouraged to investigate the scalability of this model across different academic levels, ranging from elementary education to higher education institutions, to establish a continuous developmental trajectory for innovative thinking (Gumisirizah et al., 2023). Further empirical studies employing longitudinal and mixed-methods designs are also recommended to rigorously evaluate the long-term impacts of this DT- infused framework on students' sustained academic motivation and professional readiness (Guo et al., 2020).

Declaration of generative AI in scientific writing

During the preparation of this manuscript, the authors used Generative AI technology (Google Gemini) exclusively to improve the readability and language of the text. The tool was applied with rigorous human oversight and control. The authors thoroughly reviewed, edited, and validated all language suggestions. No AI tools have been listed as authors or co-authors, and the authors remain fully responsible for the final content and integrity of this publication.

CRediT author statement

Khatesiree Sripoothorn: Conceptualization, Methodology, Investigation, Writing - original draft. **Rattana Sittioum:** Validation, Supervision, Writing - review & editing. **Buakaew Sripoothorn:** Conceptualization, Validation, Supervision.

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