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Developing student research practice through the integration of Design Thinking into Inquiry-Based Learning in STEM projects in secondary schools: A mixed-methods study

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Abstract

Participation in STEM projects is an important component of secondary education; however, students often encounter difficulties in identifying meaningful research problems and developing coherent project procedures. This study implemented a Design Thinking–Inquiry-Based Learning (DT–IBL) approach integrating human-centered and iterative design processes within an inquiry framework for secondary STEM projects. A mixed-methods design combining cohort comparison and pre–post analysis examined differences between students taught through traditional Inquiry-Based Learning (IBL) and DT–IBL, as well as students' perceptions and Levels of Use (LoU) of DT–IBL. Quantitative findings showed significant differences favoring the DT–IBL cohort in methodological design ($p = 0.035$), overall planning quality ($p = 0.003$), implementation quality ($p = 0.026$), and discussion of findings ($p = 0.014$). Qualitative evidence indicated that students engaged in human-centered and iterative processes, using user insights and feedback to refine problem definition, methodology, and project outcomes. Iterative cycles of ideation, prototyping, and testing contributed to more coherent, feasible, and contextually relevant solutions. Students also reported high levels of use of DT–IBL. Overall, the findings suggest that integrating Design Thinking within Inquiry-Based Learning supports students' STEM research practices by strengthening human-centered problem framing, methodological coherence, and iterative engagement.

Keywords: Design thinking, Human-centered, Inquiry-based learning, Level of use, Mixed methods, STEM education, STEM project.

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Contribution of this paper to the literature
This study contributes to STEM education by showing how DT–IBL supports STEM project development through iterative design and refinement. Longitudinal findings indicate growth in research competency and interest in DT. Its originality lies in comparing IBL and DT–IBL cohorts within the same Thai secondary school program.

1. Introduction

Participating in Science, Technology, Engineering, and Mathematics (STEM) projects is an essential component of secondary school education. Such projects are intended to develop students' knowledge, skills, attitudes, and motivation to pursue further studies in STEM-related disciplines (Beier et al., 2019; Butler, Lacey, Roberto, Hanney, & Luiggi, 2023; McLure, Tang, & Williams, 2022). Despite these intended benefits, effective implementation remains challenging. Many students experience difficulties in formulating appropriate research questions and defining clear project objectives (Rusmann & Ejsing-Duun, 2022; Vossen, Henze, Rippe, Van Driel, & De Vries, 2018; Vossen, Tigelaar, Henze, De Vries, & Van Driel, 2020). This critical planning stage is frequently overlooked, as students often move prematurely into development activities without thoroughly analyzing the problem context. As a result, projects may lack strong conceptual foundations, which can reduce the overall quality of the final outcomes (Markula & Aksela, 2022; Suriyabutr, Yasri, & Chenprakhon, 2026; Vossen et al., 2020).

One contributing factor is that students frequently rely primarily on existing results when identifying project topics, rather than investigating real-world needs (Christensen, Hjorth, Iversen, & Smith, 2019; Vossen et al., 2020). This tendency may lead to a solution-first approach, in which students begin developing products or experiments before fully understanding the problem or the users affected by it (Marks & Chase, 2019; Vossen et al., 2020). Consequently, students may struggle to articulate ideas, define research objectives, and justify methodological choices because the underlying problem has not been sufficiently explored (Marks & Chase, 2019; Markula & Aksela, 2022; Vossen et al., 2018; Vossen et al., 2020). Taken together, these studies suggest that a central challenge in STEM project-based learning is not merely students' ability to conduct investigations, but their difficulty in formulating meaningful, well-justified research problems. This often results in fragmented projects lacking coherence between problem, methodology, and outcomes.

To address this challenge, inquiry-based learning (IBL) and project-based approaches have been widely adopted in STEM education to engage students in scientific practices such as questioning, investigating, interpreting evidence, and designing solutions to real-world problems (Marks & Chase, 2019; McLure et al., 2022; Roehrig, Dare, Ellis, & Ring-Whalen, 2021). These approaches align with scientific and engineering practices and often integrate iterative design processes within STEM projects (Lin, Shadiev, Hwang, & Shen, 2020; McLure et al., 2022; National Research Council, 2013). While IBL effectively supports scientific reasoning, critical thinking, and evidence-based inquiry (Bybee et al., 2006; Pedaste et al., 2015), it may place less emphasis on understanding problems from the perspectives of stakeholders or end users, potentially limiting students' consideration of how challenges are experienced in real-world contexts (McCurdy, Nickels, & Bush, 2020).

One approach that addresses this need is design thinking (DT). The five-stage DT framework developed by the Stanford d.school provides a structured yet flexible approach to problem-solving (Dam & Teo, 2026; Hasso Plattner Institute of Design, 2018). DT is widely described as a human-centered and iterative methodology consisting of five phases: empathize, define, ideate, prototype, and test (Dam & Teo, 2026; Rusmann & Ejsing-Duun, 2022). Initially developed for product and innovation design, DT has since been applied across diverse fields, including education (Brown, 2008; Dam & Teo, 2026; Dotson et al., 2020).

A key characteristic of DT is its emphasis on understanding intended users and refining solutions through iterative cycles of ideation, prototyping, and testing (Bender-Salazar, 2023; Brown, 2008; Dam & Teo, 2026; Dotson et al., 2020). Through activities such as stakeholder interviews, observations, and contextual investigations, students develop a deeper understanding of problems before generating and refining solutions (Butler et al., 2023; Rusmann & Ejsing-Duun, 2022; Yu, Yu, & Lin, 2024). Previous studies suggest that DT can enhance student engagement, support the development of functional prototypes, facilitate the integration of disciplinary knowledge in STEM contexts, and strengthen the connection between problem identification and solution development through iterative refinement (Lin et al., 2020; Malele & Ramaboka, 2020; Simeon, Samsudin, & Yakob, 2022).

Although both IBL and DT have been widely applied in STEM education, they are often implemented within predefined or short-term learning activities. In contrast, this study investigates an integrated DT–IBL framework within open-ended, year-long STEM projects. The framework incorporates the human-centered and iterative characteristics of DT into inquiry-based learning, enabling students to develop research practices throughout the project process. It also compares DT–IBL and traditional IBL within the same secondary school curriculum and STEM program.

To address this gap, this study employed a mixed-methods approach to (1) compare the quality of final reports between traditional IBL and DT–IBL cohorts, (2) investigate the development of students' research practices from project proposals to final reports within the DT–IBL cohort, and (3) examine students' perceptions and Level of Use of the DT–IBL framework.

This study contributes to the STEM education literature by providing empirical evidence on the implementation of DT–IBL in open-ended secondary STEM projects and by offering comparative evidence between DT–IBL and traditional IBL within the underrepresented context of Thai secondary education.

2. Literature Review

2.1. IBL in STEM Education

IBL is widely recognized as a foundational pedagogical approach for engaging students in scientific and STEM investigations (Constantinou, Tsivitanidou, & Rybska, 2018; Sam, 2024). Grounded in constructivist principles, IBL enables learners to actively explore complex, ill-structured problems through a flexible yet systematic process (Krajcik & Blumenfeld, 2006; Roehrig et al., 2021). This process supports students in developing problem statements, generating research questions or testable hypotheses, and designing appropriate investigative procedures (Roehrig et al., 2021). Furthermore, IBL promotes the integration of conceptual understanding and scientific practices, requiring learners to coordinate knowledge and skills simultaneously during inquiry activities (Constantinou et al., 2018; Roehrig et al., 2021; Sam, 2024). Within STEM education, inquiry is often operationalized through extended, project-oriented experiences, referred to in this study as inquiry-driven STEM projects (Marks & Chase, 2019; McLure et al., 2022; Stohlmann, Moore, & Roehrig, 2012). These projects serve as a practical enactment of IBL, allowing students to engage in sustained investigations, apply interdisciplinary knowledge, and produce tangible outcomes (Butler et al., 2023; Markula & Aksela, 2022; McLure et al., 2022).

Evidence from such project-oriented implementations of inquiry indicates positive effects on student learning outcomes, including academic achievement, engagement, and problem-solving skills (Chen & Yang, 2019; Thomas, 2000; Vossen et al., 2018; Zhang & Ma, 2023). These inquiry-driven approaches emphasize student autonomy, iterative problem-solving, collaboration, and engagement with authentic contexts (McLure et al., 2022; Roehrig et al., 2021).

However, students frequently bypass this phase altogether, resulting in artifacts or prototypes that lack alignment with the underlying inquiry (Morrison et al., 2021; Vossen et al., 2020). Similarly, research in STEM design education indicates that students encounter the greatest difficulty during early stages such as problem definition and framing, which are crucial for directing subsequent design decisions (Marks & Chase, 2019; Vossen et al., 2020). When projects are based on overly broad or poorly defined problems, they tend to produce fragmented outcomes and unclear investigative processes (Markula & Aksela, 2022; Suriyabutr et al., 2026; Vossen et al., 2020).

Although authentic IBL requires engagement with complex and partially ill-defined real-world problems, this ambiguity can lead to stagnation without adequate scaffolding, particularly when students lack strategies for idea generation and iteration (Vossen et al., 2020). Without structured support, students may struggle to navigate the open-ended nature of project work, leading to confusion, reduced iteration, and limited conceptual development (Morrison et al., 2021). Consequently, effective implementation of inquiry-driven STEM projects requires not only student autonomy but also structured support, clear problem framing, and institutional backing to transition from traditional rote learning toward sustained, student-centered exploration (Markula & Aksela, 2022; Morrison et al., 2021; Nordlöf, Norström, Schönborn, & Hallström, 2024).

2.2. The Nature and Characteristics of Students' STEM Projects

Student research in STEM education is commonly implemented through project-based activities that reflect key practices of scientific and engineering inquiry (Bybee, 2013). Rather than focusing solely on completing tasks or producing artifacts, authentic STEM research involves identifying meaningful problems, investigating possible solutions, and refining ideas through evidence, testing, and feedback (Lin, Wu, Hsu, & Williams, 2021; McLure et al., 2022; Nordlöf et al., 2024).

STEM projects typically exhibit several defining characteristics aligned with authentic inquiry practices. These projects are commonly conducted through collaborative group work, enabling students to share responsibilities and engage in collective problem-solving (Marks & Chase, 2019; McLure et al., 2022; Stohlmann et al., 2012). They are often oriented around real-world problems connected to local or societal contexts (Giamellaro, Ewing, & Siegel, 2025; Malele & Ramaboka, 2020; Moore et al., 2014). Such problems encourage students to investigate challenges without predetermined solutions. A defining feature of these projects is the production of tangible artifacts, such as prototypes, reports, digital models, or presentations (McLure et al., 2022; Stohlmann et al., 2012). These artifacts represent the outcomes of students' investigations and learning processes (Awad, 2023; Rusmann & Ejsing-Duun, 2022).

The research process is inherently iterative, involving cycles of idea generation, prototyping, testing, and refinement through feedback (Morrison et al., 2021; Rusmann & Ejsing-Duun, 2022). This iterative process allows students to revisit and improve earlier ideas based on evidence and critique. As a result, the quality of student research is reflected not only in the final product but also in the development process (Marks & Chase, 2019; Roehrig et al., 2021). These iterative cycles also strengthen the relationship between the identified problem and the proposed solution (Marks & Chase, 2019; Moore et al., 2014).

In secondary education, projects in STEM and related fields take several common forms. Design-based challenges require students to construct prototypes addressing specific problems or design briefs (McLure et al., 2022; Vossen et al., 2020). At the secondary level, students may undertake independent research projects (IRPs), in which they formulate research questions, design investigative procedures, collect data, and analyze results with greater autonomy (Aflatoony, Wakkary, & Neustaedter, 2018; Bennett, Dunlop, Knox, Reiss, & Torrance Jenkins, 2018). Other forms include structured hands-on projects that support conceptual understanding of scientific phenomena, such as constructing biological or physical models (Markula & Aksela, 2022; Simeon et al., 2022; Vossen et al., 2020). In technology-focused contexts, students may also develop digital artifacts, including programs, simulations, mobile applications, or Internet-of-Things prototypes that integrate computational thinking with engineering design (McLure et al., 2022).

2.3. STEM Projects in the Thai School Context

In the Thai educational context, STEM projects are guided by the Institute for the Promotion of Teaching Science and Technology (IPST), which promotes project-based and inquiry-oriented learning approaches within specialized science and mathematics programs) (Institute for the Promotion of Teaching Science and Technology, 2009). In these programs, STEM projects are a compulsory component of the curriculum and assessment system.

At the upper secondary level, project implementation typically spans Grades 11–12. In Grade 11, students develop foundational research competencies, including literature review, data collection, and proposal development. In Grade 12, students conduct project implementation, analyze data, and communicate findings through reports and presentations. Through this progression, STEM projects aim to support students in developing research practices, including problem framing, methodological planning, and evaluation of results (Institute for the Promotion of Teaching Science and Technology, 2009).

2.4. Challenges in Conducting Projects

Despite their potential to support authentic inquiry, inquiry-driven STEM projects present several pedagogical and cognitive challenges that affect the quality and coherence of student investigations. The first challenge concerns problem definition, particularly during the initial phase of inquiry (Aflatoony et al., 2018; Morrison et al., 2021; Vossen et al., 2020). Students often struggle to formulate clear, meaningful, and researchable problems, resulting in weak conceptual foundations for subsequent investigation. When the problem is not well-defined, later stages such as the development of research questions, hypothesis formulation, and methodological design tend to lack direction and alignment (Awad, 2023; Markula & Aksela, 2022; Vossen et al., 2020).

The second challenge relates to early-stage planning and scoping of projects. Students frequently encounter difficulties in organizing the initial phases of inquiry, including narrowing the scope of investigation, identifying relevant variables, and selecting appropriate methods (Aflatoony et al., 2018). As a result, inquiry processes may become unfocused or overly broad, limiting the depth and feasibility of the investigation (Nordlöf et al., 2024; Vossen et al., 2020).

The third challenge is the lack of project unity, where different stages of the project are not coherently connected (Aflatoony et al., 2018). Empirical evidence suggests that student projects often become fragmented, with activities functioning as isolated tasks rather than as parts of a logically structured inquiry process (Aflatoony et al., 2018; Nordlöf et al., 2024). This fragmentation reduces conceptual coherence and weakens the relationship between the identified problem and the final outcomes (Markula & Aksela, 2022; Vossen et al., 2020).

The fourth challenge concerns the lack of human-centered discovery in traditional inquiry practices. Although STEM projects are frequently situated in real-world contexts, students do not consistently engage with users or stakeholders during problem exploration (Aflatoony et al., 2018). Constraints such as limited time, reliance on secondary data sources, and classroom structures often restrict opportunities for direct interaction, including interviews, observations, and user testing (Aflatoony et al., 2018; Awad, 2023; Vossen et al., 2020). Consequently, students may develop solutions that are generic or insufficiently grounded in authentic needs. Research suggests that contemporary STEM innovation increasingly emphasizes human-centered discovery, where engagement with users plays a critical role in shaping meaningful and contextually relevant solutions (Aflatoony et al., 2018; Awad, 2023; Vossen et al., 2020).

This limitation highlights a critical gap in traditional inquiry-based approaches, particularly in connecting problem identification with solution development in authentic contexts. Taken together, these challenges indicate that while inquiry-driven STEM projects provide a valuable framework for student learning, they may not sufficiently support the processes required for coherent problem framing, structured inquiry progression, and user-informed solution development. This gap underscores the need for an alternative or complementary framework that can systematically address these limitations.

2.5. Design Thinking Process

To address challenges in inquiry-driven STEM projects, particularly those related to problem definition, project coherence, and users' exploration, DT provides a structured, human-centered, and iterative approach to problem-solving (Brown, 2008; Dam & Teo, 2026; Hasso Plattner Institute of Design, 2018). In educational contexts, DT supports collaborative decision-making by encouraging learners to consider multiple perspectives throughout project development (Parker, Cruz, Gachago, & Morkel, 2021).

The DT framework consists of five stages: empathize, define, ideate, prototype, and test (Dam & Teo, 2026). During the empathize and define stages, students explore users' needs and synthesize insights into a focused problem statement (Butler et al., 2023; Dam & Teo, 2026). The ideate stage encourages the generation of multiple possible solutions, followed by the prototype, where ideas are translated into tangible models. In the test stage, students evaluate solutions and use feedback to refine both the problem and the design. Because DT is iterative, students may revisit earlier stages as new insights emerge during development (Parker et al., 2021). A systematic review further identified the define, ideate, and prototype stages as particularly important for supporting student learning and design processes (Rusmann & Ejsing-Duun, 2022; Suriyabutr et al., 2026).

2.6. DT and Student Projects

DT is widely conceptualized as a human-centered, iterative problem-solving process that enables learners to understand users, redefine problems, and develop innovative solutions through repeated cycles of ideation, prototyping, and testing (Dam & Teo, 2026; Hasso Plattner Institute of Design, 2018).

In educational contexts, particularly within STEM, DT is frequently implemented within inquiry-driven STEM projects as a structured approach to engaging students with complex, real-world challenges (Rusmann & Ejsing-Duun, 2022). Research suggests that the early stages of empathizing and defining support students in framing authentic problems and developing problem sensitivity, while the ideation stage promotes divergent thinking and creativity (Dotson et al., 2020; Marks & Chase, 2019; Rusmann & Ejsing-Duun, 2022).

The prototyping and testing stages further support iterative refinement, evidence-based decision-making, and resilience through a "fail-forward" mindset, enabling students to learn productively from early failures (Dotson et al., 2020; Marks & Chase, 2019). Empirical evidence indicates that participation in DT-based projects enhances students' knowledge construction, motivation, and self-efficacy in creativity and problem-solving (Aflatoony et al., 2018; Awad, 2023; Butler et al., 2023; Suriyabutr et al., 2026). Rather than treating projects as linear tasks to be completed, DT reframes student work as a non-linear process of continuous refinement, leading to more sophisticated, user-centered, and viable STEM solutions. Consequently, the staged yet flexible structure of DT provides a powerful scaffold for STEM project development, enabling students to navigate ill-defined problems while maintaining a clear pathway from problem exploration to tested solutions.

However, while previous studies have successfully integrated DT into student learning activities (Marks & Chase, 2019; Rusmann & Ejsing-Duun, 2022) limited research has examined its effectiveness in the context of extended, student-driven STEM projects, where students pursue project topics based on their own interests over a sustained period.

Furthermore, few studies have directly compared DT–IBL with traditional IBL in terms of students' research competencies, project coherence, and solution quality. To address this gap, this study investigates how the integration of human-centered design within a sustained, student-directed inquiry context supports students' research planning processes and enhances the coherence and quality of STEM project outcomes. Specifically, by comparing a traditional IBL cohort with a DT-integrated IBL cohort, this research demonstrates how differing pedagogical designs influence student learning and outcomes in long-term STEM project environments.

3. Materials and Methods

3.1. Research Design

This study employed a mixed-methods pre–post design incorporating both between-cohort and within-cohort comparisons. A previous cohort that experienced traditional IBL served as a reference group, while a subsequent cohort participated in DT–IBL. As cohorts were drawn from different academic years and were not randomly assigned, comparisons should be interpreted cautiously and do not permit strong causal inferences regarding the effects of DT–IBL.

The quantitative component examined students' research practices across project stages. Final reports from the DT–IBL cohort were compared with those from the IBL cohort, and within the DT–IBL cohort, initial proposals were compared with final reports to examine changes over time. Qualitative analyses of reports, proposals, progression documents, and presentations were conducted to support the interpretation of quantitative findings following a mixed-methods integration approach (Creswell & Plano Clark, 2018). Qualitative findings were used to support the interpretation of quantitative results.

Participants were 32 upper secondary students enrolled in a specialized science and mathematics program at Samsen Wittayalai School, Bangkok, Thailand. Students completed STEM projects in groups of two to three members as part of a compulsory research curriculum spanning Grades 11–12. The study involved two cohorts: a previous cohort that engaged in traditional IBL and a subsequent cohort that experienced DT–IBL.

Participation occurred within the regular curriculum. All data were anonymized, and ethical approval and informed consent were obtained from the school administration, students, and their parents or guardians.

3.2. IBL

The STEM project curriculum followed the framework established by the Institute for the Promotion of Teaching Science and Technology (2009) spanning Grades 11–12. In Grade 11, students completed a research techniques course to develop foundational research skills and subsequently undertook STEM Project 1, in which they identified research problems and prepared project proposals. In Grade 12, students continued with STEM Project 2, implementing their projects through data collection, analysis, and presentation of findings under teacher supervision. Together, these courses support a progression from research skill development to independent project implementation.

3.3. DT-IBL

The STEM project curriculum followed the IPST framework (Institute for the Promotion of Teaching Science and Technology, 2009), maintaining a consistent structure across Grades 11–12. Within the DT–IBL framework, DT was integrated into the inquiry process to support students' project development. As DT is not a standard component of the school's STEM curriculum, participating students had no formal training in DT prior to the course (Suriyabutr et al., 2026). Therefore, DT was introduced as a framework to support human-centered and iterative research practices.

Following the completion of foundational coursework in Grade 11, Semester 1, students developed project proposals while applying the five stages of DT, including empathize, define, ideate, prototype, and test within the inquiry process. During project implementation in Grade 12, students continued to apply DT in a non-linear manner, revisiting earlier stages based on feedback, preliminary findings, and emerging project needs to refine research designs, data collection strategies, and proposed solutions.

The DT stages were used to support different aspects of students' research practice.

- Empathize: Students explored user contexts through interviews and observations to understand the relevance and constraints of the problem.
- Define: Students used user insights to specify and refine the research problem and identify key variables.
- Ideate: Students generated potential solutions by synthesizing user insights with information from literature reviews.
- Prototype: Students developed initial versions of their proposed solutions or system designs.
- Test: Students evaluated their prototypes and used feedback to refine their work. When results did not meet expected outcomes or user needs, students revisited earlier stages to modify their approaches.

Across all stages, students engaged in iterative cycles of revision rather than following a fixed sequence, with feedback from users and teachers informing ongoing development. Engagement with real users also introduced considerations related to data collection practices and ethical awareness, particularly in projects involving human participants.

4. Research Instrument

4.1. Project Quality Rubric

The project quality rubric was developed based on the STEM project instructional manual used in the school, originally adapted from the Institute for the Promotion of Teaching Science and Technology (2009). The rubric was designed to assess the quality of students' research outputs across the planning and implementation phases (Appendix 1). It was constructed as an analytic rubric to accommodate the diverse nature of STEM projects, including both experimental and product-oriented work.

The planning component (25 points) consisted of five criteria: introduction, objectives, research questions and hypotheses, methodology, and ethics (5 points each). The implementation component (15 points) included results, discussion, and project uniqueness (5 points each). In total, the rubric comprised eight dimensions, each rated on a five-point scale (1 = Lowest performance, 5 = Highest performance), giving a maximum score of 40. The rubric was used to evaluate both students' project proposals and final reports.

Three experienced STEM project teachers independently evaluated the reports. Inter-rater reliability was assessed using ICC (3, k) (Shrout & Fleiss, 1979), demonstrating high agreement among raters (ICC = 0.896, 95% CI [0.805, 0.948]).

4.2. Level of use (LoU)

LoU questionnaire was developed based on Hall, Dirksen, and George (2006). The instrument was designed to assess students' engagement with research and design thinking processes throughout the STEM project.

The questionnaire comprised eight items rated on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree), representing progressive levels of design thinking use from non-use to renewal. Internal consistency was assessed using Cronbach's alpha. After reverse scoring the negatively worded item, the questionnaire demonstrated good reliability (Cronbach's α = 0.80, 95% CI [0.69, 0.90]). The results are presented as percentage distributions of students' perceived levels of design thinking use throughout the STEM project.

5. Data Collection and Analysis

Data collected from the research instruments were analyzed using both quantitative and qualitative approaches. The analysis was organized according to the research questions to ensure alignment between the study objectives, data sources, and analytical methods.

All 32 students in the DT-IBL cohort participated in the instructional intervention and completed the relevant research instruments; therefore, their data were included in the quantitative analysis for level of use. In addition, students' project reports were analyzed to examine the quality of research outputs across cohorts.

A total of 20 project reports were included in the analysis, comprising 12 reports from the IBL cohort and 8 reports from the DT-IBL cohort (Table 1). Although 12 project reports were originally produced in the DT-IBL cohort, 4 computer science projects were excluded. These projects were evaluated primarily based on software development and coding processes, including technical implementation and system design, and were assessed by computer science teachers using subject-specific criteria, such as oral examinations. As such, their evaluation criteria differed from the common assessment framework applied in this study. Therefore, only project reports evaluated using a common, rubric-based framework grounded in the school's STEM project criteria were included in both the qualitative and report-based quantitative analyses.

Table 1. Group of students and project names.

Cohort	Group	Number of students	Project name
IBL	IBL 1	3	Garlic Peeling Machine
	IBL 2	3	Portable Vortex Mixer
	IBL 3	2	Effect of 1-Methylcyclopropene (1-MCP) on Delaying the Wilting of Orchid Flowers
	IBL 4	3	Comparative Study of Mechanical Properties of Calcium Caseinate Films Incorporated with Pectin and Carrageenan
	IBL 5	3	Development and Efficiency Comparison of a Prototype Wheelchair Transfer System for Disabled Individuals
	IBL 6	3	Development of Impact-Absorbing Composite Sheets from Cotton Fabric Coated with Pre-Vulcanized Latex and Epoxy Resin
	IBL 7	2	Fabrication and Characterization of Gelatin Sheets Derived from Tilapia Scales
	IBL 8	2	Design and Construction of an Automatic Airbag System for Fall Injury Prevention
	IBL 9	3	Development of Gluten-Free Cereal from Riceberry Rice for Health-Conscious Consumers
	IBL 10	3	Nutritional and Sensory Evaluation of Gluten-Free Riceberry-Based Cereal
	IBL 11	2	Development of an Automated Patient Repositioning System Using Air Pressure Mechanism
	IBL 12	3	Development of a Hybrid Bullet-Resistant Armor Using X-ray Film, Stainless Steel, and Cornstarch-Based Non-Newtonian Fluid
Total	12	32	
DT-IBL	DT-IBL1	3	Inulin as Fat Substitute for Mayonnaise Development
	DT-IBL2	2	Stainless Steel Comparison for Dental Crowns
	DT-IBL3	3	Smart Farm for Controlling Salinity in Grape Seaweed Cultivation
	DT-IBL4	3	Zinc Oxide and Lead Oxide Ratio for Preserving Century Eggs
	DT-IBL5	3	Oil Absorption Paper from Rice Straw
	DT-IBL6	3	Automatic CPR Machine for Elderly in Retirement Homes
	DT-IBL7	2	Response of Mealybugs
	DT-IBL8	3	CO2 Gas Capture and Removal System
Total	8	20	

5.1. Research Question 1: A Comparative Analysis of Final Report Quality Between Traditional IBL and DT-IBL

To examine differences in students' research practice, final reports from the IBL and DT-IBL groups were analyzed using a standardized project quality rubric. Three experienced teachers independently evaluated all reports (Appendix 1), including those from the DT-IBL cohort (n = 8) and the IBL cohort (n = 12), collected across multiple academic years.

For the DT-IBL cohort, both research proposals and final reports were analyzed to identify the extent of development throughout the project process.

Quantitative data derived from rubric scores were analyzed using descriptive statistics to compare overall performance and specific dimensions of research practice between the two groups.

In addition, a qualitative analysis of report components conducted to explicitly interpret patterns in how students developed their projects across two main phases: planning and implementation. This analysis focused not only on presenting evidence but also on identifying where and how improvement occurred. The planning phase consisted of five dimensions: (1) problem framing and the development of research questions and hypotheses, (2) inquiry design and ideation in objective development, (3) methodological planning, and (4) ethical considerations.

The implementation phase consisted of four dimensions: (1) Iterative testing and refinement, (2) result presentation in IBL and DT-IBL, (3) discussion and interpretation in IBL and DT-IBL, and (4) uniqueness of the project. The analysis focused on comparing how research practices were demonstrated in the final reports of the IBL and DT-IBL groups. It examined variations in problem framing, methodological coherence, and the alignment between research objectives and outcomes across the two cohorts. These qualitative comparisons provided an overall understanding of differences in research practice between the two cohorts.

5.2. Research Question 2: An Investigation into the Development of Student Research Practice in Conducting STEM Projects Through The DT-IBL Framework

To investigate the development of students' research practice, both quantitative and qualitative methods were employed.

Quantitatively, three teachers evaluated students' project proposals and final reports using the project quality rubric to examine changes between the initial and final stages of the projects. Qualitatively, progression reports, presentations, project proposals, and final reports were analyzed to examine how students' research practices developed over time. The analysis focused on three dimensions: (1) human-centered aspects in DT–IBL, (2) project development over time, and (3) improvement in clarity and structure from proposal to final report.

First, human-centered aspects were examined by identifying how students incorporated stakeholder perspectives and user needs into their research. This included evidence of progression from general problem identification toward research questions and solutions that responded to real-world contexts through empathy and user engagement.

Second, project development over time was examined by comparing documents across project stages to track how students' research focus, objectives, and methodological approaches evolved from initial proposals to final reports.

Third, improvement in clarity and structure was examined by analyzing the coherence and alignment among problem statements, research objectives, methodologies, and evaluation. This included how students developed increasingly integrated and operationalized research designs across project stages.

These three dimensions were applied consistently across all documents. In the Results section, each dimension is presented through analytical descriptions supported by representative excerpts from students' work.

5.3. Research Question 3: How Do Student Participants Perceive Their Level of Use of the Designed Learning Activity After Participating in the Class?

To examine students' perceived engagement in research practice, data collected from the LoU questionnaire were analyzed using quantitative methods.

Responses were analyzed using percentage distributions to determine students' levels of engagement across the different stages of use. The analysis focused on identifying the proportion of students at each level, ranging from lower levels of use to higher levels.

In addition, the percentage distribution of responses across levels of use was analyzed to identify overall patterns of engagement and to determine whether students demonstrated progression toward more advanced and adaptive use of the DT in conducting project.

6. Results

6.1. Research Question 1: A Comparative Analysis of Final Reports between IBL and DT-IBL

Research question 1 examined differences in the quality and characteristics of students' final reports between cohorts taught using traditional IBL and DT-IBL.

6.1.1. Quantitative Finding

Group comparisons were conducted using the Mann–Whitney U test on rubric-based evaluation scores derived from school assessment criteria. The current cohort (DT-IBL; $n = 8$) was compared with a previous cohort (IBL; $n = 12$) (Table 2).

Quantitative analysis comparing the final reports of the two cohorts revealed differences in both the planning and implementation components of students' research work. As shown in Table 2, the DT-IBL cohort achieved significantly higher scores in the overall planning component ($U = 83.50$, $p = 0.003$). Within this component, the methodology section showed a statistically significant difference ($U = 71.000$, $p = 0.035$), with DT-IBL students demonstrating stronger procedural planning and clearer alignment between research objectives and experimental design. In contrast, no statistically significant differences were found for the introduction, objectives, or research question components ($p \geq 0.05$).

Differences were also observed in the implementation phase of the final reports. The DT-IBL cohort achieved significantly higher scores in the overall implementation component ($U = 73.500$, $p = 0.026$), particularly in the discussion section ($U = 76.500$, $p = 0.014$), indicating stronger interpretation of results and reflection on research outcomes. No statistically significant difference was observed in the results section ($p = 0.137$), although the uniqueness component showed a positive trend favoring the DT-IBL cohort ($U = 67.50$, $p = 0.061$).

6.1.2. Qualitative Findings: Processes Underlying Improvement in Research Practice

To complement the quantitative results, qualitative analysis was conducted to examine the processes underlying students' development in research competencies. Student artifacts, including proposals, progression reports, final reports, and presentations, were analyzed to trace how their research practices evolved over time.

The analysis focused on iterative development, refinement of research ideas, and the incorporation of human-centered and ethical considerations. These findings provide insight into how the DT-IBL framework supported changes in students' research practice beyond quantitative outcomes.

Table 2. The comparison between IBL and DT-IBL cohorts.

Dimension	IBL Cohort				DT-IBL Cohort				Total	P
	Min.	Mean	Max.	SD	Min.	Mean	Max.	SD		
Introduction	4.000	4.417	4.667	0.207	4.333	4.542	4.667	0.173	5.000	0.096
Objective	3.000	3.750	4.333	0.452	3.333	4.042	4.667	0.486	5.000	0.134
Research question and hypothesis	1.000	3.139	4.000	1.105	2.667	3.500	3.667	0.356	5.000	0.584
Methodology	3.000	3.972	4.333	0.437	3.333	4.292	4.667	0.452	5.000	0.035*
Ethics	-	0.667	-	0.000	0.667	3.583	4.667	0.181	5.000	0.000
Summary of planning parts	12.667	15.944	18.000	1.746	15.000	19.958	22.333	2.633	25.000	0.003*
Result	3.000	3.667	4.000	0.492	3.333	4.000	5.000	0.667	5.000	0.137
Discussion	2.333	3.194	4.333	0.643	3.000	3.875	4.667	0.502	5.000	0.014*
Uniqueness	3.000	3.611	4.333	0.343	3.333	3.875	4.333	0.354	5.000	0.061
Summary of implementing parts	9.667	10.472	12.334	1.298	15.000	11.750	14.000	1.065	15.000	0.026*

Note: $p < 0.05$, * indicates statistically different.

a) Planning Phase

The planning phase in the project of this study includes how students frame the introduction, objective, research question and hypothesis, methodology, and ethics.

- Problem framing and the development of research questions and hypotheses.

Both cohorts generally followed a similar report structure from school format, progressing from background information to research objectives, questions, and hypotheses. However, differences emerged in how information gathered during problem framing informed subsequent project components. In the DT–IBL cohort, hypotheses also described relationships between variables and outcomes and, in some cases, incorporated references to application contexts and user-related considerations. This information was subsequently reflected in the development of research questions and hypotheses. For example, DT–IBL 6 developed a prototype of a CPR device for use in elderly nursing homes. The group first reviewed relevant literature identifying incorrect CPR performance as a major contributor to unsuccessful outcomes. They then interviewed staff members in an elderly nursing home and found that caregivers often lacked sufficient CPR knowledge and experience. These findings informed the problem statement presented in the introduction section:

"Due to health and living challenges in nursing homes, such as staff shortages and limited expertise, the authors propose developing an automated cardiac compression device to reduce caregiver burden and improve survival rates for elderly patients with cardiac arrest." (DT–IBL 6)

Evidence from progression reports and presentations further suggested that information gathered during problem framing contributed to the formulation of research questions and hypotheses. For example, DT–IBL 1 investigated mayonnaise containing inulin as a fat substitute. Information regarding obesity among younger populations and students' daily consumption habits informed the refinement of project objectives and hypotheses, including considerations related to consumer acceptance. The group proposed the following hypotheses:

"1. Inulin can be used as a substitute for oil in mayonnaise production. 2. Different ratios of inulin and oil will result in differences in the properties of mayonnaise. 3. Mayonnaise produced with different ratios of inulin and oil will result in differences in consumer satisfaction." (DT–IBL 1)

In contrast, projects in the IBL cohort generally relied on literature review and relationships between experimental variables when framing problems and developing hypotheses. For example, one IBL project hypothesized.

"Films containing pectin or carrageenan additives will exhibit different physical properties." (IBL 4)

Although both cohorts followed comparable structural patterns, DT–IBL projects appeared more likely to carry information gathered during problem framing into the subsequent development of research questions and hypotheses, whereas IBL projects tended to focus primarily on relationships between experimental variables.

- Inquiry design and ideation in objective development: linear investigation in IBL and iterative exploration in DT–IBL.

In terms of research objectives, similarities were observed in the overall structure of objectives across the IBL and DT–IBL cohorts, while differences emerged in their level of detail and emphasis.

In the DT–IBL cohort, research objectives were often formulated based on both literature review and user or contextual considerations. In addition to specifying the purpose of prototype development, these projects more frequently identified variables and conditions for testing, as well as aspects related to user evaluation or application. For example, one project investigating mayonnaise production included.

"1. To study the production of mayonnaise containing inulin and oil at different ratios. 2. To test the properties of mayonnaise containing inulin and oil at different ratios. 3. To evaluate consumer satisfaction." (DT-IBL 1)

In contrast, objectives in the IBL cohort were generally focused on prototype development or testing, with less detail regarding variables or user-related considerations. As mentioned in the final report.

"1. To design and develop a prototype airbag system. 2. To test the performance of the prototype airbag system". (IBL 11)).

Overall, while both cohorts followed a similar structural format for presenting research objectives, differences were observed in how the objectives were specified. DT–IBL projects tended to include more detailed and context-related elements, whereas IBL projects focused more on prototype performance without explicitly linking to user needs or application contexts. These findings indicate variation in how research objectives were formulated across the two groups.

- Methodological planning: procedural approaches in IBL and application-oriented approaches in DT-IBL

Differences between cohorts were evident in methodological planning presented in the final reports. In both groups, methodologies were generally developed to address the stated hypotheses; however, differences emerged in the extent to which methodological plans incorporated evaluation criteria and revision processes.

For example, DT–IBL 4 organized its methodology into three stages: preparation of pickling solutions, production of century eggs, and evaluation of product properties. Evaluation criteria included comparisons with commercial products, measurement of gelled egg white proportion, pH values, and residual lead content using a standard test kit.

"The properties of the century eggs were evaluated at two time points, after 14 and 30 days of curing, using multiple criteria: color, gelled egg white proportion, pH value, and residual lead content." (DT–IBL 4)

Progression reports further indicated that procedures were revised throughout the project based on comparisons between expected and observed outcomes. Information obtained from interviews, observations, and comparisons with existing products appeared to provide additional reference points that students could revisit when refining methodological plans.

In contrast, methodologies in the IBL cohort were more frequently presented as sequences of technical procedures. For example, one project investigating hot-air-dried Wolffia compared protein content at different drying temperatures using spectrophotometric analysis and standard calibration curves. As described in the report:

"Measure absorbance using a spectrophotometer at 540 nm and calculate protein concentration using a standard calibration curve." (IBL 10)

Although both cohorts followed structured procedures, DT–IBL projects appeared more likely to demonstrate alignment among objectives, procedures, and evaluation criteria. Consideration of intended users, together with information from interviews, observations, and existing products, may have provided reference points that helped students maintain coherence throughout project development. In contrast, IBL projects tended to emphasize technical processes and experimental comparisons.

- Ethical considerations: implicit treatment in IBL and explicit integration in DT-IBL.

Differences between cohorts were also observed in how ethical considerations were addressed in student reports. In the DT–IBL cohort, ethical aspects were more explicitly integrated into the project design. Reports often included a dedicated section outlining considerations related to stakeholder engagement, prototype testing, or data collection. These elements were presented as part of the design process, reflecting attention to the potential impact of the project on users and contexts.

In contrast, reports from the IBL cohort generally did not include a distinct section on research ethics. References to ethical considerations were either absent or embedded implicitly within other sections, without being articulated as a specific component of the inquiry process.

These patterns suggest a difference in how ethics was positioned within the projects: in DT–IBL, ethical considerations were more explicitly incorporated as part of the design and inquiry process, whereas in IBL, they were less visible as a defined element of project development.

b) Implementation phase

Qualitative analysis of students' project documentation, including progression reports, presentations, and final reports, revealed differences between the IBL and DT-IBL cohorts during the implementation phase.

In the DT-IBL cohort, implementation was linked to user-related considerations identified during earlier stages of the project. Evidence from progression reports and presentations showed that students referred to information from observations, interviews, or comparisons with existing products when conducting experiments and evaluating results.

In addition, the implementation process in the DT-IBL cohort was not presented as strictly linear. Changes observed between initial plans, progression reports, and final reports indicated that students revised their methods and procedures during the project. These revisions were documented as adjustments to experimental conditions, materials, or evaluation approaches.

In the IBL cohort, implementation was generally presented as a sequence of experimental steps and outcomes. References to user-related information or modifications during the process were observed in some reports but were less frequently documented in the available data.

- Iterative testing and refinement: Method-Oriented Iteration in IBL and User-Oriented Iteration in DT-IBL

Project documentation from the DT-IBL cohort consistently demonstrated iterative cycles during prototype development and experimental implementation. Progression reports showed that students revisited procedures, modified experimental designs based on preliminary findings, and refined prototypes to improve performance.

For instance, in a seaweed farming project, students developed a device to regulate salinity in aquaculture environments. After constructing an initial prototype, they tested it under varying conditions and adjusted the design upon identifying performance limitations. These refinements were followed by further testing, illustrating a clear iterative process. For example, the record in the progression report of the DT-IBL group students originally designed a wide range of ponds for seaweed and the system. They did not mention the concrete idea about how to add fresh water to represent rainfall, as mentioned in the progression report.

"A control system was newly developed and programmed to interface with a salinity sensor. Rainfall events were expected to reduce salinity levels; therefore, when the measured salinity fell below a predetermined threshold, the system automatically activated the inflow of seawater through a pipeline into the cultivation pond until the salinity returned to the desired level (progression report of DT-IBL 3)."

Following prototype testing, the students finalized their design, established procedures for regulating freshwater input and salinity levels, presented a schematic diagram of the prototype, and developed a water control system.

A similar iterative approach was evident in a project investigating inulin as a fat substitute in mayonnaise. Students experimented with different ratios of inulin and oil, evaluated texture and stability, and refined formulations based on observed physical properties until achieving results comparable to commercial products.

Notably, in Group DT-IBL 1, iterative development was further informed by user-centered considerations. The group began by exploring dietary behaviors among young people and identifying relevant health concerns. Through user interviews, they gained insights into consumption patterns, which guided both formulation adjustments and product development decisions, including alignment with user preferences and comparisons with commercial mayonnaise. This integration of experimental evidence and user feedback reflects a more holistic iterative process.

In contrast, reports from the IBL cohort generally presented experimental procedures as a linear sequence following the initial plan. Although some groups reported modifications to their prototypes, these changes were typically driven by technical performance rather than user needs. For example, in the garlic peeling machine project, students focused on increasing the quantity of garlic peeled. While improvements were documented, there was limited consideration of user-related factors, such as intended use or context of application. As a result, iterative refinement was less explicit and less systematically integrated into the implementation process.

- Result presentation in IBL and DT-IBL: consistent approaches to data description and evidence-based reporting.

Although differences were observed in the discussion sections, the presentation of experimental results showed similar patterns across both cohorts. In both groups, students reported quantitative measurements, summarized experimental outcomes in tables or figures, and described observed trends in the data. These similarities correspond with the quantitative findings indicating no statistically significant difference in scores for the results component between the two cohorts.

Overall, qualitative evidence from project reports and progression documents indicated differences between the two cohorts in how experimental procedures were implemented and how results were interpreted. Both groups present results, but they could be presented more clearly and accurately, or the data analysis could be more thorough to support the conclusions.

- Discussion and interpretation in IBL and DT-IBL: descriptive approaches in IBL and evidence-based interpretation in DT-IBL.

Differences between cohorts were evident in the discussion sections of the final reports. In the IBL cohort, interpretations primarily focused on describing observed trends and relationships within the collected data, with limited reference to previous studies or existing products. For example, IBL 5 developed a wheelchair prototype aimed at assisting caregivers and patients in making transfers easier. Although the project evaluated three transfer methods and identified side transfer with a removable armrest as the most efficient approach, the discussion lacked comparison with existing commercial or standard wheelchairs. As stated in their report:

"From the efficiency testing of the wheelchair, three transfer methods were compared: side transfer without removable armrest, transfer at a 45-degree angle, and side transfer with a removable armrest. The results showed that the side transfer with a removable armrest required the least time and energy. The 45-degree transfer and the side transfer without a removable armrest required progressively more time and energy. Therefore, the side-opening wheelchair transfer is the most efficient method (IBL-5)."

Although the group demonstrated effective evaluation of their prototype, the absence of positioning their findings in relation to existing designs, user contexts, and relevant literature limits the strength and generalizability of their conclusions.

In contrast, discussion sections in the DT–IBL cohort more frequently connected experimental findings with previous research studies or theoretical explanations. For example, DT–IBL 1 interpreted the results of replacing oil with inulin:

"The findings align with prior studies on the use of inulin as a fat substitute. Previous research reported that 'inulin can partially replace oil, resulting in reduced energy content' while maintaining product stability (Bhattacharya, 2022; Peasura, Sinchaipanit, & Sangsuriyawong, 2023). In addition, the mayonnaise produced showed acceptable physical properties, including a 'pale yellow color' and a pH of approximately 3, which meets industrial standards. However, differences in stability were observed, with some formulations exhibiting phase separation. Consumer preference results further indicated that formulation 2 was the most favored, whereas other formulations showed oil separation, suggesting lower product acceptability." (DT–IBL 1)

Differences were also observed in the suggestion sections. Suggestions from the IBL group generally focused on improving the reliability and comprehensiveness of the current study. For example:

"5.3.1 Additional experimental methods should be explored to obtain more standardized and reliable data. 5.3.2 More than two evaluation criteria should be considered to enhance the overall effectiveness and comprehensiveness of the project." (IBL-2)

In contrast, suggestions in the DT–IBL cohort more frequently translated findings into design modifications. For example, DT–IBL 6 suggested.

"5.3.2 The experimental results also indicated that the compression force of the device decreased over time after initial operation. The project team and advisor concluded that the pump should be improved or replaced with one that has a higher airflow rate. This is because the pump used in this experiment did not provide sufficient airflow to maintain pressure, resulting in reduced piston performance during later stages of operation." (DT–IBL 6)

These findings suggest differences in how students interpreted and utilized experimental evidence. While IBL projects primarily emphasized describing results and strengthening the current investigation, DT–IBL projects appeared more likely to connect findings with previous studies and use evidence to inform iterative design improvements.

- Project uniqueness: theory-based approaches in IBL and practical, user-focused approaches in DT-IBL.

The uniqueness of projects in both cohorts showed similar patterns, with variations in how ideas and approaches were developed. Across the documents, projects from both cohorts addressed real-world problems and applied existing knowledge or techniques within specific contexts.

Projects from both cohorts addressed real-world problems and adapted existing knowledge or techniques within specific contexts. However, differences emerged in how project ideas were framed and refined. In the DT–IBL cohort, project development was more frequently guided by intended users and iterative refinement processes. Progression reports and presentations indicated that information obtained from users informed the selection of materials, design features, and evaluation criteria, and projects were revised through repeated testing to better align with user expectations. For example, one group developed a CPR machine by adapting a piston-based mechanism for use with a patient model. The design was modified throughout the project, and testing was conducted using a CPR model to evaluate its practicality and performance. In contrast, IBL projects more often emphasized theoretical understanding, scientific principles, and measurable outcomes. For example, one group developed a garlic peeling machine and primarily evaluated its effectiveness based on the number of garlic cloves peeled, without explicitly considering variations in garlic shape or practical user requirements.

Across both cohorts, projects frequently involved adapting or applying existing methods and knowledge. However, DT–IBL projects appeared more likely to use human-centered considerations as a framework for guiding iterative refinement, whereas IBL projects tended to prioritize theoretical and technical aspects of project development.

6.2. Research Question2: An Investigation into the Development of Student Research Practice in Conducting STEM Projects Through the Integrated DT-IBL Framework

Research question 2 examined the development of students' competency in conducting STEM projects by comparing their proposal and final report scores within the DT-IBL cohort.

6.2.1. Quantitative Finding

Quantitative analysis revealed significant improvement in the overall planning component in the final report ($p = 0.002$). Significant gains were found in methodology ($p = 0.002$), objectives ($p = 0.012$), and introduction ($p = 0.021$), indicating better research design, clearer objectives, and improved contextualization (Table 3).

In contrast, no significant difference was found in the research question and hypothesis component ($p = .205$), likely because students had already developed relatively clear and concrete research questions at the proposal stage.

Overall, the findings indicate that students improved in structuring and designing their research, while their research questions remained relatively stable across both stages.

6.2.2. Qualitative Findings of the Differences Between the Proposal and Final Project Report

To examine the development of students' research practice within the DT-IBL cohort, this study compares students' initial project proposals with their final reports to explore how their work changed over time. The findings reflect an ongoing process in which students refined their ideas through feedback, testing, and revision.

The analysis is organized into three dimensions: development over time, human-centered aspects, and clarity and professionalism. These dimensions provide a general framework for understanding how students' research practice progressed from initial ideas to more developed and coherent projects. The following sections present each dimension in detail, describing key patterns observed across stages and supported by selected student excerpts.

Table 3. Comparison between students' scores in proposal and final report from DT-IBL cohort.

Dimension	Proposal				Final report				Total	P
	Min.	Mean	Max.	SD	Min.	Mean	Max.	SD		
Introduction	4	4.333	4.667	0.207	4.333	4.542	4.667	0.173	5	0.021*
Objective	2.667	3.375	3.667	0.452	3.333	4.042	4.667	0.486	5	0.012*
Research question and Hypothesis	0.667	2.958	3.667	1.105	2.667	3.5	3.667	0.356	5	0.205
Methodology	1.926	3.296	3.889	0.437	3.333	4.292	4.667	0.452	5	0.002*
Sum of Planning part	10.333	14.333	16.667	1.746	15	19.958	22.333	2.633	20	0.002*

Note: $p < 0.05$, * indicates statistically significant.

- Human-centered aspects in DT-IBL: increasing emphasis from proposal to final Report.

This dimension examines how stakeholder perspectives informed the refinement of project focus throughout the DT–IBL process. In the early stages, projects were often framed broadly without clearly specifying the intended application context. DT–IBL 2 provides a representative example. In the initial proposal, the project was positioned within dental treatment contexts without distinguishing between large hospitals and small dental clinics. However, after conducting interviews with practicing dentists, the group identified challenges faced by small dental clinics, including limited equipment, higher treatment costs, and reliance on external dental crown production services.

"Interviews with practicing dentists indicated that small dental clinics experience significant constraints in equipment and treatment costs. Therefore, this study focuses on developing a dental crown solution suitable for small-scale clinical settings." (DT–IBL 2 progression report)

This refinement was also reflected in the project objectives. While the proposal broadly focused on producing dental crowns and examining changes after sintering, the final report incorporated more specific fabrication parameters and measurement criteria:

"1. To produce stainless steel dental crowns with different resolutions (250 and 400 micrometers) using a 3D printer. 2. To investigate changes in physical properties, including hardness and dimensional changes (size), as well as microstructural characteristics, including surface features of sintered parts, microstructure of stainless-steel dental crowns, and the resolution of the developed stainless steel crown components after sintering." (DT–IBL 2 final report)

These differences are documented across project stages, where earlier versions present general descriptions of production and evaluation, while later versions include defined parameters, detailed measurement criteria, and clearer references to application context and user needs.

Corresponding differences were also observed in the methodology sections. Comparisons between proposal documents and final reports in the DT–IBL cohort show changes in the level of detail and structure of procedural descriptions across stages of the project. This pattern suggests that students' research practices became more responsive to user needs and more contextually grounded, as stakeholder perspectives were increasingly incorporated into the development of their research. Such progression can be observed across multiple groups and corresponds to documented activities throughout the DT process.

- Project development over time in DT-IBL: from proposal to final report.

This dimension examines how students' research practices evolved from initial proposals to final reports. Early project documents often presented broad problem descriptions and limited methodological detail. As projects progressed, students refined problem definitions, narrowed project scope, and developed more structured research designs through iterative revision. DT–IBL 3 provides a representative example. In the early stages, the group identified transportation as a major factor affecting sea grape quality based primarily on a literature review.

"Literature review mentions that currently, there are two main methods for transporting sea grapes (Caulerpa lentillifera): transporting after removing excess water from the sea grapes and packing sea grapes into containers or bottles for transportation." (DT–IBL 3 progression report)

However, interviews with sea grape farmers and vendors revealed that transportation was not the primary concern. Instead, freshwater contamination following rainfall was identified as a more significant challenge affecting salinity and causing economic losses.

"Interviews with local SMEs and sea grape farmers revealed that heavy rainfall during the rainy season significantly reduces water salinity in earthen ponds, leading to large-scale mortality and economic losses. Current mitigation practices, including manual drainage and subsequent seawater replenishment, were found to be time-consuming and lacking precision in salinity control. This problem highlights the need for a more efficient and accurate system to regulate salinity in sea grape cultivation." (DT–IBL 3 proposal)

This refinement was also reflected in the methodological design presented in the final report, which included clearly defined testing procedures and measurable conditions.

"3.2.3.1 Distilled water was added to reduce the salinity of the solution in the pond to approximately 30 ppm. 3.2.3.2 The smart farm salinity control system… was then activated. 3.2.3.3 Observations were conducted to determine whether the system operated when the measured salinity dropped below 29 ppm…" (DT–IBL 3 final report)

These changes suggest that iterative revision within the DT process supported students in refining project focus, narrowing application contexts, and developing more operationalized research designs over time. Pilot testing further informed modifications to procedures and evaluation criteria, leading to more detailed objectives and methodologies in final reports, although some research questions remained broadly similar to those proposed initially.

- Improvement in clarity and structure in DT-IBL reports from proposal to final report.

This dimension examines how students' research practices became more coherent over time, reflected in the alignment among problem statements, objectives, methodologies, and evaluation. While some early-stage projects showed fragmented structures, later-stage reports demonstrated clearer integration across these components. DT–IBL 1 provides a representative example. Comparisons between the proposal and final report illustrate this progression. In the proposal, evaluation dimensions were identified, but procedures remained broadly described:

"3.4 Physical property analysis: the physical properties to be examined include viscosity, pH (using a universal indicator), and energy value. 3.4.1 Measurement of viscosity: to be conducted by … 3.4.2 Measurement of pH: to be conducted by …" (DT–IBL 1 Proposal).

In contrast, the final report presented clearly operationalized procedures with specified methods and measurable conditions: "3.3.3 Physical and chemical property analysis of mayonnaise... 3.3.3.1 pH measurement was conducted using a universal indicator... 3.3.3.2 Stability was measured using a centrifuge at 3500 rpm for 15 minutes..." (DT–IBL 1 Final Report)

This progression demonstrates clearer alignment among objectives, methodologies, and evaluation, resulting in a more coherent and operational research design.

Thus, the findings from research question 2 show that students' research practice developed across the DT-IBL process in three interrelated dimensions. First, students incorporated stakeholder perspectives into their work, leading to more context-specific problem definitions. Second, students demonstrated development over time, with increasing clarity in research focus, objectives, and methodological design from initial proposals to final reports. Third, students' work showed a shift in clarity and professionalism, reflected in the unity of the project, where problem statements, objectives, methods, and evaluation became more clearly aligned and operationally defined.

6.3. Research Question 3: How Do the Student Participants Perceive the Level of Use of the Designed Activity After Participating in Class?

This section examines students' perceptions of their level of use of the designed learning activity after participating in the class. The analysis addresses research question 3 by investigating how students perceived their engagement with the DT-IBL approach during their projects. Students' perceptions were measured using a LoU questionnaire adapted from Hall et al. (2006) (Table 4).

The results indicate that students generally perceived DT as a useful approach for conducting STEM projects. For Item 1, which stated that learning STEM projects using the D-school five-step DT process is not useful, the majority of students strongly disagreed (78.125%), and overall, 93.750% selected disagreement responses (Levels 1–2), while only 3.125% expressed agreement (Level 4). This indicates that students overwhelmingly did not perceive the approach as ineffective.

Items 2–5 examined students' interest and intention to apply DT in their project work. For Item 2, 81.250% of students selected ratings of 4 or 5, indicating increased interest in using DT for their own projects. Similarly, Item 3 showed that 75.000% of students reported willingness to use DT in future projects. For Item 4, 84.375% of students agreed that they would use DT to guide how they conduct projects. Item 5 showed a comparable pattern, with 78.125% indicating that DT could be used to plan different stages of project work.

Items 6–8 assessed students' perceived confidence in using DT independently and in future contexts. For Item 6, 84.375% of students reported confidence in their ability to apply DT to successfully complete a project. In contrast, Item 7 showed lower levels of agreement, with 50.000% indicating confidence in teaching others, while 37.500%

selected a neutral response. Finally, Item 8 showed that 93.750% of students expressed confidence in applying DT to future projects or innovations.

The distribution of responses across all items indicates high levels of perceived usefulness, interest, intention for continued use, and confidence in applying the DT approach, although confidence in teaching others remained comparatively lower.

Table 4. Percentage distribution of students' responses on the LoU of the DT-IBL.

	Topics	Level				
		1	2	3	4	5
1	I think that learning STEM projects with the D-School five-step DT is not useful.	78.125	15.625	3.125	3.125	0.000
2	I have started to be interested in using the D-School five-step DT as a tool for conducting my own projects.	3.125	3.125	12.500	59.375	21.875
3	I might use the five-step DT when I have time to conduct a project.	0.000	3.125	21.875	50.00	25.000
4	I will use the D-School five-step DT to design how I conduct a project.	0.000	3.125	12.500	46.875	37.500
5	I will use the D-School five-step design thinking process to design and plan every step of conducting a project.	3.125	0.000	18.750	50.000	28.125
6	I am confident that I can use the D-School five-step design thinking process to design and successfully complete a project.	0.000	0.000	15.625	46.875	37.500
7	I am confident that I can teach my friends how to use the D-School five-step design thinking process to design and conduct a project.	0.000	12.500	37.500	34.375	15.625
8	I am confident that I can apply the D-School five-step design thinking process to design future projects or innovations.	0.000	0.000	6.250	56.250	37.500

7. Discussion

This study aimed to examine differences in students' research practice between IBL and DT–IBL approaches, as well as the development of research practice over time. The findings indicate that while both approaches supported structured project work, the DT–IBL framework was associated with more contextually grounded, coherent, and application-oriented research practices. This section discusses the underlying mechanisms that may explain these patterns.

7.1. Human-Centered and Iterative Processes in DT–IBL

The findings indicate that while both approaches supported structured project work, the DT–IBL framework led to more contextually grounded, coherent, and application-oriented research practices. These differences can be explained by the integration of DT stages and iterative processes. The DT stages enabled students to understand users while exploring potential solutions, whereas iterative loops supported continuous refinement. Together, these elements shaped how students framed problems, designed methods, and refined their project outcomes (Dotson et al., 2020; Markula & Aksela, 2022; Suriyabutr et al., 2026).

A key difference lies in how problems were initially defined. In the DT–IBL group, the empathize and define stages encouraged students to engage with users and real-world contexts through interviews, observations, and other inquiry methods. By combining literature with stakeholder perspectives, students moved beyond broad, topic-based ideas toward more focused and meaningful problem definitions grounded in actual needs. Rather than moving directly to solutions, students were encouraged to examine root causes and refine their understanding of the problem before developing research objectives and methodological plans. These findings are consistent with previous studies showing that the empathize and define stages help students understand stakeholders, connect projects to authentic contexts, and strengthen problem framing in STEM learning (Bender-Salazar, 2023; Dam & Teo, 2026; Dotson et al., 2020; Lin et al., 2020; McCurdy et al., 2020).

Importantly, these early stages were not linear. As highlighted by Suriyabutr et al. (2026), the empathize and define stages operate through iterative loops, allowing students to revisit and refine their understanding as new insights emerge. Students often returned to these stages as their understanding of users developed. For instance, learners may initially define a problem based on assumptions, but after gathering user feedback, they refine or even redefine the problem to better reflect real needs (Suriyabutr et al., 2026). This iterative process helped prevent premature closure, where students commit too early to a single idea without sufficient exploration (Dotson et al., 2020; Marks & Chase, 2019; Suriyabutr et al., 2026). As a result, students developed clearer research objectives and stronger alignment between their projects and real-world applications.

In contrast, students in the traditional IBL cohort mainly relied on literature-based approaches to guide their investigations. While this approach supports conceptual understanding and scientific reasoning by connecting prior knowledge with new knowledge (Krajcik & Blumenfeld, 2006; Roehrig et al., 2021), it provides fewer opportunities to refine research problems through direct engagement with real-world contexts. Consequently, students may find it more difficult to develop focused research questions that reflect contextual considerations alongside scientific knowledge (Lin et al., 2020; Vossen et al., 2020).

These differences were further reflected in students' development from proposal to final report. Initial proposals were often broad and primarily informed by literature. As students progressed through the DT process, iterative refinement helped them narrow project scope, strengthen research questions, and improve methodological design over time (Awad, 2023; Dam & Teo, 2026; Rusmann & Ejsing-Duun, 2022; Suriyabutr et al., 2026).

The contribution of DT–IBL became more evident during the ideation, prototyping, and testing stages. During ideation, students explored multiple possible solutions before selecting a research direction, reducing premature closure and supporting more informed decision-making (Dam & Teo, 2026; Marks & Chase, 2019; Saikatikorn, Wannapiroon, & Nilsook, 2026). The prototype and test stages then enabled students to evaluate early solutions, identify limitations, and refine both their designs and methodological approaches through repeated cycles of evidence and stakeholder feedback (Dotson et al., 2020; Parker et al., 2021).

Consistent with Suriyabutr et al. (2026), these later DT stages operated through non-linear iterative loops, allowing students to revisit earlier phases as new evidence emerged. Rather than functioning as simple repetition, iteration supported continuous refinement of procedures and strengthened the alignment among research objectives, methodologies, and intended applications. Students who engaged in more complete iterative cycles produced projects with higher originality and feasibility, reinforcing the importance of sustained iteration throughout the DT process (Suriyabutr et al., 2026).

In contrast, the IBL approach tended to follow a more linear investigation process. Students typically established procedures early based on prior studies and implemented them with limited revision. Although this approach supports systematic inquiry, it provides fewer opportunities to revisit assumptions, explore alternative solutions, or refine methodological decisions in response to emerging evidence and contextual information (Chin et al., 2019; Markula & Aksela, 2022).

Taken together, these findings suggest that the effectiveness of DT–IBL depends not only on the inclusion of the DT stages but also on students' sustained engagement in iterative processes across those stages. This is consistent with prior research showing that deeper and more continuous iteration leads to stronger outcomes (Chin et al., 2019; Fang & Fan, 2026; Marks & Chase, 2019). By integrating empathizing, defining, ideating, prototyping, and testing within inquiry, DT–IBL supported the development of more coherent, contextually grounded, and applicable STEM project outcomes.

7.2. How Do the Student Participants Perceive the Level of Use of the Designed Activity After Participating in Class?

The findings for research question 3 indicate that students reported generally positive perceptions of the DT–IBL framework, particularly regarding its usefulness and their confidence in applying it to future projects. High levels of agreement were observed in items related to using DT–IBL in their own work, suggesting strong acceptance of the approach and its perceived relevance for future use. These findings are consistent with previous studies reporting that participation in design thinking activities encourages students to apply similar approaches in other contexts (Butler et al., 2023; Lin et al., 2020). Together, these findings suggest that integrating DT into IBL provides a structured yet flexible process that supports students' readiness to engage in complex, real-world problem solving (Butler et al., 2023; Lin et al., 2020).

In contrast, lower responses were observed for items related to teaching or adapting DT–IBL for others. This pattern may reflect students' current role as learners, as higher levels of use, such as adapting or teaching an approach, are often associated with more advanced or professional roles (Hidayat & Saad, 2025). Thus, students appeared ready to apply DT–IBL in their own future work, while demonstrating more limited confidence in transferring the approach to others.

Future research could explore whether extended exposure to DT–IBL or additional scaffolding supports progression toward higher levels of use, particularly in adapting and transferring the approach across contexts (Marks & Chase, 2019; Morrison et al., 2021; Roehrig et al., 2021).

8. Conclusion

This study suggests that integrating DT within IBL may support students in conducting STEM projects by providing a human-centered framework for considering intended users alongside inquiry-based processes. The findings indicate that students in the DT–IBL cohort demonstrated more coherent research practices, while iterative refinement appeared to contribute to clearer alignment among research problems, objectives, methodologies, and evaluation.

Students also reported positive perceptions of the DT–IBL approach, particularly regarding its potential application in future STEM contexts. Lower confidence in teaching the approach to others may reflect their current role as learners rather than instructors.

Overall, the DT–IBL framework offers a structured yet flexible approach for supporting students' research practices and engagement with real-world problem-solving. However, given the non-randomized design and differences in available documentation between cohorts, these findings should be interpreted as indicative associations rather than evidence of causal effects.

9. Limitation

One limitation of this study is the use of two cohorts from different academic years rather than random assignment. Although both cohorts followed the same curriculum and STEM program, differences between cohorts may have been influenced by cohort characteristics or contextual factors unrelated to the instructional approach. Therefore, the findings should be interpreted cautiously and do not permit strong causal inferences regarding the effects of the DT–IBL framework.

The primary limitation of this study lies in the asymmetry of available documentation between the two student cohorts. While the development of the DT–IBL cohort was documented through multiple sources, including progress reports, presentations, and final reports, the data available for the traditional IBL cohort consisted primarily of final reports.

As a result, the analysis of students' research practices, particularly the examination of iterative processes, is constrained by the available evidence. Specifically, the extent to which students revisited and refined earlier stages of their work cannot be directly compared across cohorts due to the absence of equivalent process documentation for the IBL group. Consequently, the qualitative comparisons presented in this study are based solely on the available evidence.

To avoid overinterpretation, this study does not assume that the IBL cohort did not engage in iterative processes; rather, it acknowledges that such processes cannot be fully traced without supporting documentation. This limitation highlights the importance of consistent data collection across cohorts.

Future research should address this limitation by implementing longitudinal designs that systematically document student project development over time, including process-oriented evidence such as progress reports, reflections, and presentations. Such approaches would enable more comprehensive comparisons of students' research practices across different instructional frameworks.

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Appendix

Appendix 1.

Table A1. Rubric for evaluation of final report.

Topics	Scale				
	1	2	3	4	5
Introduction	Unclear. Does not indicate the background information, brief overview of research methods, hypothesis or expected results no significant contribution to the field.	Show the background information, but does not give brief overview of research methods, hypothesis or expected results no significant contribution to the field but includes the problem statement	Show the background information, give a brief overview of research methods, but do not include hypotheses or expect no significant contribution to the field. But include the problem statement	Show the background information, give brief overview of research methods, but do not include hypotheses or expected results no significant contribution to the field. But include the problem statement	The introduction effectively sets the context for the research give brief overview of research methods, includes the hypothesis or expect result show significant contribution to the field. Clearly states the research question or problem.
Research objective	Unclear	Self-driven without rationales	Self-driven with real-world problems	Self-driven with real-world problems with literature support	Real-world problem with literature support from multiple sources
Research question and hypothesis	The purpose and research question are not stated or are completely unclear.	The purpose and research question are poorly defined, not specific to the main focus of the research, unmeasurable, unachievable, or do not address the goal of research.	The purpose and research question are somewhat unclear but can be inferred from the abstract.	The purpose and research question are mostly clear, but some clarification is needed.	The purpose and research question are clearly stated and easy to understand.
Methodology	The methods used are poorly designed and not appropriate for the research question.	The methods used are poorly designed and not appropriate for the research question.	The methods used are somewhat appropriate but have significant weaknesses.	The methods used are mostly rigorous and appropriate, but some weaknesses are present.	The methods used are rigorous and appropriate for the research question.
Ethical consideration	The ethical considerations are not addressed or are disregarded, putting participants and the integrity of the research at risk.	The ethical considerations are not adequately discussed, or appropriate measures are not taken to protect participants and maintain the	The ethical considerations are satisfactory, but they could be improved by providing more in-depth analysis or addressing additional ethical concerns.	The ethical considerations are addressed, but they could be more thoroughly discussed or more measures taken to protect participants and maintain the	The ethical considerations are thoroughly discussed, and appropriate measures are taken to ensure the protection of participants and the integrity of the research.

Topics	Scale				
	1	2	3	4	5
		integrity of the research.		integrity of the research.	
Results	The data analysis does not back up the results, which makes it hard to understand what the conclusions are.	The results are not clearly presented or accurately reported, and the data analysis is inadequate to support the conclusions.	The results are satisfactory but could be improved by providing more detailed data analysis or more complete representation of the results.	The results are presented, but could be more clearly and accurately, or the data analysis could be more thorough to support the conclusions.	The results are shown clearly and correctly, and the data is analysed well to back up the conclusions.
Discussion	The discussion is poorly written and fails to provide any meaningful interpretation or recommendations for future research.	The discussion is weak and fails to effectively interpret the results or provide clear implications and recommendations for future research.	The discussion is satisfactory but could be improved by providing more detailed interpretation of the results or more specific recommendations for future research.	The discussion interprets the results and places them in context but could be more in-depth or clearer in stating the implications and including the existing literature from reliable resources, which cannot be articles, and also recommendations for future research.	The discussion effectively interprets the results and places them in the context of the existing literature that is published in reliable publications and clearly states the implications and recommendations for future research.
Uniqueness	The research is not original and plagiarises the work of others.	The research is not original and makes little to no new contribution to the field.	The research is satisfactory but could be improved by including more original ideas or methods.	The research makes a contribution to the field, but could be more original or innovative in its ideas or methods with somewhat innovative	The research makes a unique and original contribution to the field, and the ideas and methods used are innovative with creativity and innovative.