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A Scaffolded Journey: The Impact of an End-to-End Design Thinking Model on Creative Confidence and Self-Efficacy in Middle School Interdisciplinary STEAM Project-Based Learning

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Abstract

This investigation explored the influence of a comprehensive Design Thinking (DT) framework, integrated into an interdisciplinary Science, Technology, Engineering, Arts, and Mathematics (STEAM) Project-Based Learning (PBL) curriculum, on middle school students' creative confidence and learning self-efficacy. Using an explanatory sequential mixed-methods approach, the study involved 78 seventh-grade students (aged 12–13) from an international school in Abu Dhabi who participated in a nine-week interdisciplinary project titled "Sustainable Urban Spaces: Designing for Accessibility." Quantitative data were gathered using a Modified Creative Confidence Scale (MCCS) and a Project-Based Learning Self-Efficacy Survey (PBL-SES), administered before and after the intervention. Qualitative data were collected through digital portfolios, focus-group interviews, and instructional field notes. Paired-samples t-tests revealed statistically significant improvements in both creative confidence [$t(77) = 14.23$, $p < .001$, $d = 1.11$] and learning self-efficacy [$t(77) = 16.85$, $p < .001$, $d = 1.23$]. Thematic analysis identified three core themes: (a) the metacognitive reinterpretation of failure, (b) scaffolding as a mechanism for cognitive support, and (c) interdisciplinary synthesis achieved through authentic problem-solving. These findings suggest that embedding Design Thinking within STEAM-PBL offers a structured approach that bolsters both cognitive and affective learning outcomes. This study provides an empirically validated instructional model for curriculum developers aiming to foster innovation, resilience, and interdisciplinary knowledge transfer in middle school educational contexts.

Keywords: Creative confidence, Design thinking, Middle school education, Project-based learning, Self-efficacy, STEAM education.

1. Introduction

In contemporary education, there is a growing demand for pedagogical frameworks that effectively bridge the divide between theoretical knowledge and practical application. Traditional, compartmentalized instruction frequently falls short of equipping students with the complex problem-solving capabilities essential for an increasingly interconnected global society. Interdisciplinary STEAM (Science, Technology, Engineering, Arts, and Mathematics) education has emerged as a robust response to this challenge, intentionally dismantling disciplinary boundaries to cultivate holistic learning [Yakman, 2008]. When implemented through Project-Based Learning (PBL), STEAM enables students to engage with authentic, complex questions over extended periods, thereby grounding content standards in meaningful contexts [Krajcik & Shin, 2014]. However, while conventional PBL establishes a strong foundation for student inquiry, it often lacks an explicit, human-centered methodology to guide students through the inherently complex process of innovation. Without a structured creative process, middle school students can easily become overwhelmed by open-ended challenges, potentially leading to superficial solutions or premature disengagement [English, 2017]. This pedagogical gap underscores the need for a complementary framework that scaffolds the cognitive and creative dimensions of problem-solving. Integrating Design Thinking (DT) into the PBL environment addresses this need by offering a structured, empathetic, and highly iterative pathway for student inquiry [Carroll et al., 2010]. Design Thinking, characterized by its sequential phases of empathizing, defining, ideating, prototyping, and testing, imbues PBL with a deeply human-centered purpose. By prioritizing empathy from the outset, students learn to develop solutions for real individuals with tangible needs, transforming the project from a mere academic checklist into a purposeful mission [Razzouk & Shute, 2012]. Furthermore, the iterative nature of DT, particularly its emphasis on "failing forward" through rapid prototyping and testing, normalizes making mistakes. This cyclical process directly cultivates student self-efficacy and resilience, converting setbacks into valuable opportunities for critical metacognition and reflection [Zimmerman, 2000]. The middle school years (typically ages 11–14) represent a crucial developmental period during which this integrated approach can be exceptionally impactful. During this transitional stage, students experience significant cognitive shifts, developing an increased capacity for abstract reasoning, spatial awareness, and social empathy [Steinberg, 2014]. Simultaneously, this age group often exhibits a documented decline in

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academic engagement and creative confidence when instruction feels disjointed or inflexible. Introducing a structured DT-PBL framework at this juncture capitalizes on students' expanding social awareness and cognitive abilities, channeling their energy into collaborative, high-agency learning experiences [Henriksen et al., 2017]. Despite the theoretical synergy between Design Thinking and STEAM-PBL, widespread classroom implementation remains a considerable challenge for educators. Many teachers find it difficult to balance the open-ended nature of creative design with the rigorous structural scaffolding that middle schoolers require to progress from initial exploration to refined, insightful application. Existing literature frequently extols the abstract benefits of innovation in education but often fails to provide empirical, end-to-end curricular models that precisely illustrate how to scaffold this journey across multiple disciplines [Kim et al., 2021]. To address this gap, the present study investigates the empirical implementation of a comprehensive, highly scaffolded Design Thinking model within a middle school interdisciplinary STEAM-PBL curriculum. By meticulously documenting the structural milestones, instructional scaffolds, and student outcomes throughout an entire project lifecycle, this paper offers a concrete blueprint for educational practitioners and curriculum designers. Ultimately, this research aims to demonstrate how a deliberate combination of empathy, structure, and iteration can elevate middle school projects from simple activities into powerful catalysts for lifelong innovation and creative confidence.

2. Literature Review

The imperative to equip middle school learners with advanced cognitive competencies—such as critical thinking, creative resilience, and interdisciplinary problem-solving—has prompted significant structural transformations in modern curriculum design. Traditional pedagogical approaches frequently isolate science, technology, engineering, arts, and mathematics into independent silos, thereby limiting students' capacity to transfer and apply knowledge to real-world scenarios [Henriksen, 2017]. To counteract this fragmentation, interdisciplinary STEAM education has emerged as a prominent instructional framework that explicitly integrates artistic and design-based methodologies into technical fields [Sancomb, 2024]. When contextualized within Project-Based Learning (PBL), STEAM provides an authentic, inquiry-driven environment in which students engage with complex, "wicked problems" over extended periods [Auh, 2026]. However, effectively managing the open-ended nature of these projects requires rigorous pedagogical structures to prevent student disengagement and cognitive overload. While PBL establishes an effective framework for open-ended inquiry, researchers observe that traditional project structures often lack a clear, human-centered roadmap to guide generation and refinement processes [Ananda et al., 2023]. Middle school students, who are undergoing unique socio-emotional and cognitive transitions, frequently encounter difficulties when moving from abstract problem identification to practical implementation [Skovronskyi, 2025]. Without deliberate process scaffolding, the open learning environment of a STEAM project can lead to superficial solutions or premature resignation in the face of early failures [Saseendran & Thomas, 2025]. This operational deficit underscores the value of integrating Design Thinking (DT) as an explicit structural scaffold within the broader PBL lifecycle. Design Thinking addresses this limitation by introducing a flexible, sequential methodology centered on five distinct phases: empathy, problem definition, ideation, prototyping, and testing [Morrin & Liston, 2020]. By incorporating "empathy" at the project's inception, DT shifts students' motivation from merely fulfilling academic requirements to addressing authentic human needs [Yüksel, 2025]. This human-centered orientation redefines technical engineering or scientific challenges as purposeful social missions. Furthermore, empirical studies indicate that embedding design thinking into STEAM curricula significantly enhances student fluency, original idea generation, and analytical reasoning compared with conventional instruction [Skovronskyi, 2025]. A key advantage of a DT-infused PBL framework is its emphasis on iterative prototyping and systematic feedback loops. Traditional classroom projects often follow a linear progression toward a single, high-stakes final product, which can inadvertently foster a fear of failure and inhibit creative risk-taking. In contrast, the iterative cycles inherent in Design Thinking reframe failure as an informative instructional mechanism [Wang, 2025]. By developing low-resolution prototypes and subjecting them to user testing, middle school students cultivate a healthier response to mistakes, thereby nurturing creative confidence and learning self-efficacy [Yin, 2021]. This cyclical pattern of "designing, testing, and pivoting" encourages deep metacognition, compelling students to reflect continuously on why a particular iteration was unsuccessful and how cross-disciplinary STEAM knowledge can optimize the subsequent variant.

Despite the theoretical congruence among Design Thinking, STEAM, and Project-Based Learning, successful implementation in the middle school classroom remains a persistent challenge. Teachers often experience considerable apprehension about facilitating open-ended design practices while simultaneously maintaining curricular alignment and classroom order [Henriksen, 2017]. Many existing models provide broad, abstract justifications for design integration but fail to supply specific, scaffolded curricular blueprints that teachers can reliably implement [Saseendran & Thomas, 2025]. Consequently, STEAM instruction can sometimes devolve into superficial arts-and-crafts activities that lack meaningful connections to technical learning objectives or rigorous user testing. This study directly addresses this implementation gap by investigating a highly scaffolded, end-to-end Design Thinking model structurally embedded within a middle school interdisciplinary STEAM-PBL curriculum. By examining the precise milestones, continuous assessment mechanisms, and structural scaffolds across an entire project lifecycle, this paper provides an empirical blueprint for educational practitioners. Ultimately, this literature review underscores that, when intentionally scaffolded, design thinking transcends a simple brainstorming exercise to become a robust framework that transforms middle school projects into authentic catalysts for student innovation, empathy, and resilience.

3. Research Model and Conceptual Framework

The conceptual architecture of this study is founded on the strategic integration of three primary educational paradigms: Kilpatrick's (1918) Project Method, Yakman's (2008) framework for integrative STEAM education, and the five-stage Design Thinking model of Stanford's Hasso Plattner Institute of Design (d.school). While traditional Project-Based Learning provides the overarching macro-structure (e.g., timeline and external milestones), it frequently exhibits a "process gap" in which students lack a structured strategy for creative execution. This study

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proposes an integrated model in which the iterative, micro-level phases of Design Thinking are directly embedded within the macro-stages of PBL. This structure ensures that the open-ended nature of interdisciplinary STEAM exploration is bounded by rigorous cognitive and human-centered scaffolds.

3.1. The Conceptual Framework Matrix

The relationship among the macro-pedagogy (PBL), the operational engine (Design Thinking), and the learner's cognitive/affective dimensions is conceptualized as a highly scaffolded matrix. Rather than treating these methodologies as parallel tracks, the model integrates the five phases of Design Thinking directly into the standard project lifecycle, providing the explicit scaffolding mechanism that drives interdisciplinary integration. The alignment among stages, phases, scaffolds, disciplinary targets, and outcomes is summarized in Table 1.

Table 1. Alignment of project-based learning stages, Design Thinking phases, scaffolds, STEAM targets, and student outcomes.

PBL Macro-Stage	Embedded Design Thinking Phase	Core Scaffolding Mechanism	Interdisciplinary STEAM Target	Primary Student Outcome
1. Launch & Inquiry	Empathize	User Persona Mapping & Interviews	A / S (Art/Social Context)	Human-Centered Purpose
2. Problem Framing	Define	"How Might We" (HMW) Statements	S / T / E / M (Problem Boundary)	Analytical Clarity
3. Interdisciplinary Ideation	Ideate	Divergent/Convergent Matrix	S / T / E / A / M (Cross-pollination)	Ideation Fluency
4. Iterative Development	Prototype	Low-Fidelity Modeling & Fabrication	E / T (Engineering/Tech)	Creative Resilience
5. Evaluation & Refinement	Test	User Feedback Grids & Optimization	M / S (Data Analysis/Math)	Metacognitive Reflection

3.2. System Dynamics of the Research Model

The research model functions as a dynamic input-process-output system. This system illustrates how the introduction of explicit scaffolds modifies the traditional project environment to foster enhanced student competencies. The model is illustrated in Figure 1.

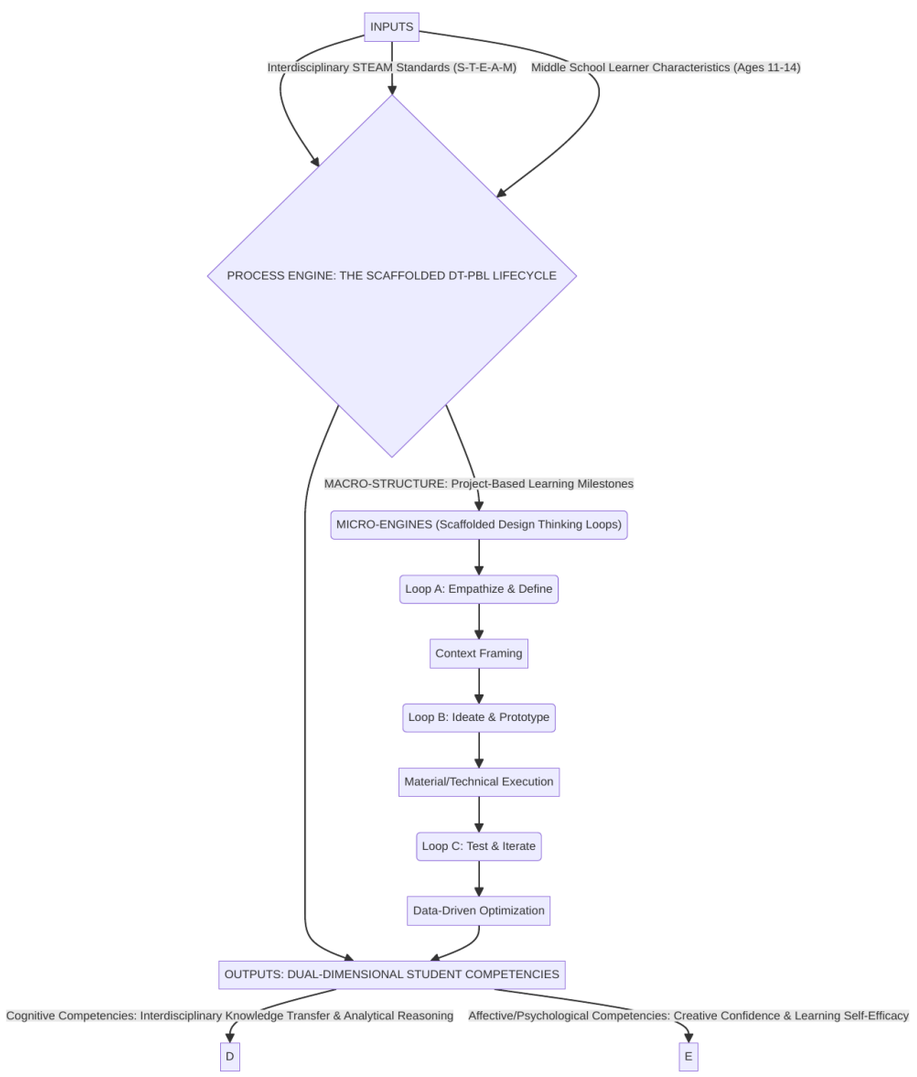


Figure 1. Research model for integrating scaffolded Design Thinking within STEAM project-based learning.

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3.2.1. The Process Loops

The core innovation of this model resides in the Process Engine, which replaces the conventional linear project trajectory with three distinct, iterative sub-loops:

The Context Framing Loop (Empathize & Define): Students employ qualitative methods (such as empathy interviewing and observation) to ground their scientific or technical problem in human terms. The "Arts" (A) component of STEAM is used here for ethnography, communication design, and ethical positioning. The Material/Technical Execution Loop (Ideate & Prototype): Students translate abstract cross-disciplinary concepts into physical or digital manifestations. In this loop, engineering (E) and technology (T) standards are naturally engaged as tools necessary to construct students' concepts, rather than as abstract, isolated exercises. The Data-Driven Optimization Loop (Test & Iterate): Students subject their low-fidelity models to user testing, collecting qualitative and quantitative data. This stage requires mathematical reasoning (M) and scientific inquiry (S) to analyze user feedback grids and optimize the technical performance of their final deliverables.

3.3. Theoretical Hypotheses / Research Propositions

Based on this structural arrangement, the study operates under a central pedagogical thesis: the ultimate success of interdisciplinary STEAM-PBL in middle school environments is directly contingent upon the presence of an internal, end-to-end process scaffold (Design Thinking). In the absence of this internal engine, projects tend to gravitate toward uncritical execution. When explicitly present, this scaffold modifies student outcomes across two primary dimensions. Proposition 1: Cognitive Optimization via Scaffolding. Explicitly aligning Design Thinking phases with PBL milestones minimizes cognitive overload for the 11–14 age group. By deconstructing a vast, open-ended problem into sequential, actionable cognitive tasks (e.g., transitioning from broad brainstorming to structured, constraints-based ideation), the framework provides a protective cognitive architecture. This structure enables students to achieve higher levels of interdisciplinary knowledge transfer and more sophisticated problem definition without being overwhelmed by the task's complexity. Proposition 2: Affective Resilience via Iteration. The normalization of prototyping and testing within the curriculum fundamentally reshapes middle schoolers' relationship with academic failure. This iterative process reframes mistakes as valuable learning opportunities, fostering resilience and a growth mindset. By encouraging repeated cycles of design, testing, and refinement, students develop a healthier perspective on setbacks, which in turn enhances their creative confidence and learning self-efficacy.

4. Methodology

To evaluate empirically the implementation and efficacy of the scaffolded, end-to-end Design Thinking model within a middle school interdisciplinary STEAM-PBL curriculum, this study adopted a rigorous mixed-methods approach. A mixed-methods design is particularly well suited to educational intervention research, as it allows for the quantitative measurement of shifts in student competencies alongside the qualitative exploration of the instructional processes and experiences that drove those changes [Creswell & Creswell, 2018].

4.1. Research Design

This study employed an explanatory sequential mixed-methods design within an action research framework. Action research enables the researcher-practitioner to investigate contemporary classroom interventions systematically while maintaining high environmental validity [Mertler, 2019]. The quantitative phase used a quasi-experimental pre-test/post-test design without a control group, focusing on tracking growth within a bounded cohort across a single, complete project lifecycle (nine weeks). The qualitative phase followed immediately, employing thematic analysis of student portfolios, semi-structured interviews, and instructional field notes to elucidate, contextualize, and enrich the quantitative findings. The study sequence is summarized in Figure 2.

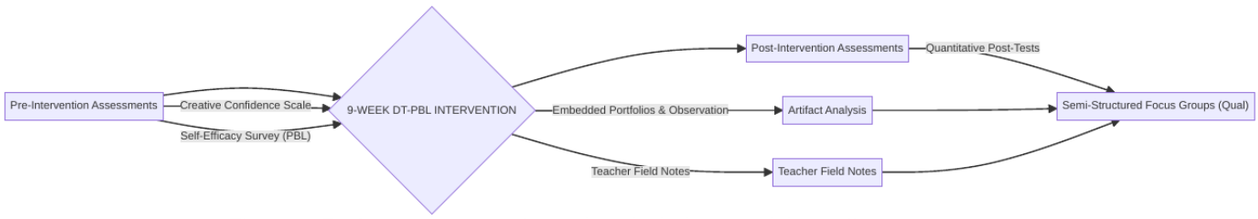


Figure 2. Explanatory sequential mixed-methods design and data-collection sequence.

4.2. Setting and Participants

The study was conducted at an urban, co-educational middle school in Abu Dhabi, United Arab Emirates, that implements an international, interdisciplinary curriculum framework. The school features purpose-built learning spaces, including a specialized STEAM fabrication lab equipped with digital design tools, 3D printers, and traditional prototyping materials.

4.2.1. Participant Demographics

A purposive sampling strategy was employed to select participants actively enrolled in the integrated STEAM-PBL core block. The final sample comprised 78 seventh-grade students (aged 12–13) distributed across three distinct classroom sections, all following the same curriculum framework.

Gender Distribution: 42 female students (53.8%) and 36 male students (46.2%).

Language Profile: 65% of participants were classified as English as an Additional Language (EAL) learners, reflecting the diverse international student body.

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Instructional Context: Students collaborated in stable, heterogeneous teams of 4 to 5 members, carefully assembled by the instructional team to balance academic performance, digital literacy skills, and social dynamics.

4.3. The Instructional Intervention

The intervention consisted of a structured, nine-week interdisciplinary STEAM project titled "Sustainable Urban Spaces: Designing for Accessibility." The project challenged student teams to identify a physical or structural accessibility barrier within their local community and engineer a functional, prototyped solution. The instructional timeline was rigorously scaffolded to ensure that students devoted a specific number of academic hours to each distinct phase of the Design Thinking lifecycle, aligning directly with the conceptual framework of this study. The phase-by-week sequence is illustrated in Figure 8.

4.3.1. Curricular Scaffolding Timeline

Weeks 1–2: The Empathy Phase. Students conducted primary qualitative interviews with community members, mapped user personas, and engaged in field observations to understand the physical realities of individuals with varying mobility challenges (Targeting Arts/Social Context). Week 3: The Define Phase. Teams synthesized their qualitative findings into synthesis grids, progressing from broad observations to concrete, actionable "How Might We" (HMW) statements that delineated their specific engineering problem (Targeting Analytical Clarity). Week 4: The Ideate Phase. Students participated in structured brainstorming routines, using a divergent-convergent matrix to cross-pollinate scientific concepts, technological possibilities, and artistic expressions before selecting a single team solution (Targeting Cross-pollination). Weeks 5–7: The Prototype Phase. Teams transitioned into the STEAM fabrication lab. They translated their design sketches into progressively complex forms—advancing from low-fidelity cardboard/clay models to digital or physical scale prototypes using basic electronics and computer-aided design (CAD) software (Targeting Engineering/Technology). Weeks 8–9: The Test & Iterate Phase. Prototyped solutions underwent user simulation testing. Teams gathered data on mechanical durability, ease of use, and functional performance, analyzing feedback grids to implement mathematical and structural refinements before their final public presentation (Targeting Data Analysis/Math).

4.4. Data Collection Tools

To ensure a robust data convergence model, four distinct data collection instruments were deployed over the course of the nine-week study.

4.4.1. Quantitative Instruments

Modified Creative Confidence Scale (MCCS): A 12-item Likert-scale instrument adapted from Beghetto [2006] was designed to measure students' self-perceptions of their creative potential and adaptability within problem-solving contexts. It was administered immediately before Week 1 and immediately after Week 9.

Project-Based Learning Self-Efficacy Survey (PBL-SES): An 8-item survey adapted from standard self-efficacy metrics [Zimmerman, 2000] focused specifically on students' perceived capability to navigate open-ended tasks, collaborate effectively, and manage setbacks without losing academic motivation. It was administered before and after the intervention.

4.4.2. Qualitative Instruments

Digital Process Portfolios: Student teams maintained a continuous digital logbook throughout the project lifecycle. These portfolios documented raw brainstorming materials, photographs of successive prototype iterations, reflections on unsuccessful tests, and rationales for structural design modifications.

Semi-Structured Focus Group Interviews: Upon project completion, four focus group interviews were conducted ($n = 24$ students in total, representing a stratified sample of students with high, medium, and low growth on the quantitative scales). Interview protocols focused on students' perceptions of the scaffolded stages, moments of frustration, and the cognitive strategies employed to navigate prototype failures.

4.5. Data Analysis Methods

Quantitative and qualitative data streams were analyzed independently using separate specialized paradigms before being integrated during the final interpretation stage to address the core research propositions.

4.5.1. Quantitative Analysis

Descriptive statistics (means and standard deviations) were calculated for both the MCCS and PBL-SES pre- and post-intervention scores. To evaluate the statistical significance of shifts in students' creative confidence and learning self-efficacy, paired-samples t-tests were performed.

Paired-samples t-test formula: t = mean difference / (SD of differences / $\sqrt{n}$).

Effect sizes were computed using Cohen's d to determine the practical magnitude of the instructional intervention, with $d > 0.8$ interpreted as a large effect size [Cohen, 1988]. All quantitative processing was completed using statistical analysis software, with the alpha level for significance set a priori at $p < .05$.

4.5.2. Qualitative Analysis

The qualitative data—comprising focus group transcripts, student portfolio reflections, and instructional field notes—were analyzed using a systematic inductive Thematic Analysis approach, following the six-phase framework established by Braun and Clarke [2006].

1. Phase 1: Verbatim transcription of focus group recordings and familiarization with the data corpus.
2. Phase 2: Generation of initial open codes at the sentence level (e.g., "frustration with material limits," "pivoting after user critique").

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3. Phase 3: Identification of broader patterns among the codes to construct tentative, overarching candidate themes.
4. Phase 4: Review and refinement of themes against the raw data to ensure structural alignment.
5. Phase 5: Definition and naming of clear thematic categories (e.g., The Metacognitive Shift in Failure Perception, Scaffolds as Cognitive Anchors).
6. Phase 6: Selection of compelling anchor quotes to construct the narrative results.
To ensure trustworthiness, qualitative validity was maintained through data source triangulation, a detailed audit trail of coding choices, and member-checking of focus group summaries with participant representatives.

5. Exemplar Project Case Study: Sustainable Urban Spaces

5.1. Project Overview

Project Title: Sustainable Urban Spaces: Designing for Accessibility
Target Grade: Grade 7 (Ages 12–13)
Duration: 9 Weeks (45 Instructional Hours)
The Driving Challenge: How can we, as empathetic designers, use STEAM principles to re-engineer a local public space so that it is universally accessible and environmentally sustainable?

5.2. Phase-by-Phase Matrix Walkthrough

Step 1: The Launch and Inquiry Phase (Weeks 1–2)
PBL Milestone: Entry Event & Initial Inquiry
Embedded DT Phase: Empathize
STEAM Disciplines Engaged: [A] Arts / Social Context & [S] Science



Figure 3. Empathy-phase sequence: wheelchair simulation, community interviews, and user-persona mapping.

5.2. The Scaffolding Mechanism

The project begins with an immersive experience. Students are tasked with navigating school grounds or a simulated obstacle course using wheelchairs, crutches, or visual impairment goggles. This immediate physical experience is complemented by training in qualitative research. Student teams conduct structured interviews with school staff, parents, or local residents who experience mobility, visual, or auditory challenges. The empathy sequence is summarized in Figure 3.

5.3. STEAM Integration in Action

Students draw on [A] Arts / Social Context to move beyond their personal experiences and cultivate authentic empathy. They create visual User Persona Maps and empathy diagrams that illustrate the emotional, psychological, and physical barriers encountered by their users. Concurrently, [S] Science is introduced through an investigation of human biology—specifically the skeletal and muscular systems—to develop a scientific understanding of physical strain, range of motion, and sensory processing limitations.
Step 2: The Problem Framing Phase (Week 3)
PBL Milestone: Defining the Project Boundary
Embedded DT Phase: Define
STEAM Disciplines Engaged: [S] Science & [T] Technology

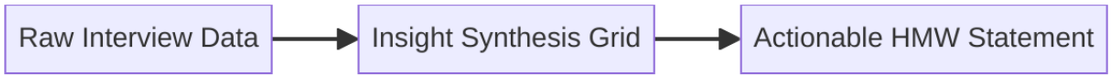


Figure 4. Problem-framing sequence: raw interview data, insight synthesis, and an actionable "How Might We" statement.

5.4. The Scaffolding Mechanism

Faced with a substantial volume of qualitative interview data, middle school students can easily experience cognitive overload. To guide them, teachers provide a structured Insight Synthesis Grid. Teams organize raw data into three categories: User Needs, Physical Constraints, and Environmental Factors. This structural scaffolding helps students narrow a broad problem into a highly precise, actionable "How Might We" (HMW) statement. The framing sequence is shown in Figure 4.

5.5. STEAM Integration in Action

Teams use [T] Technology to aggregate, tag, and sort their qualitative findings using cloud-based collaborative tools. They apply [S] Science (Environmental Ecology) to evaluate the sustainability parameters of their chosen urban space, considering factors such as urban heat islands and solar exposure.

Example Student HMW Statement: "How might we re-engineer the community park entrance so that wheelchair users can independently navigate the incline while using sustainable, solar-powered materials for nighttime visibility?"

Step 3: The Interdisciplinary Ideation Phase (Week 4)
PBL Milestone: Project Planning & Proposal Development
Embedded DT Phase: Ideate
STEAM Disciplines Engaged: [S] Science, [E] Engineering, and [A] Arts

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Figure 5. Ideation sequence: divergent brainstorming, constraints-matrix assessment, and concept selection.

5.6. The Scaffolding Mechanism

To prevent student teams from prematurely settling on the first simple idea, teachers employ a strict Divergent-Convergent Matrix. During the divergent step, teams are required to use sketchpads to generate at least 20 diverse, unconventional solutions. During the convergent step, they filter these ideas through a Constraints Matrix, scoring each idea from 1 to 5 based on physical safety, material availability, and alignment with sustainability principles. The ideation sequence is shown in Figure 5.

5.7. STEAM Integration in Action

This stage serves as the primary interdisciplinary bridge. Students integrate [S] Material Science (analyzing properties such as friction, durability, and load-bearing capacity of various materials), [E] Engineering (applying the structural principles of levers, pulleys, and inclined planes), and [A] Arts (aesthetic design) (using spatial rendering, color theory, and industrial design principles to ensure that the solution is welcoming and integrates seamlessly into the urban landscape).

Step 4: The Iterative Development Phase (Weeks 5–7)

PBL Milestone: Product Research and Prototyping

Embedded DT Phase: Prototype

STEAM Disciplines Engaged: [E] Engineering and [T] Technology



Figure 6. Prototype progression from a low-fidelity cardboard model to a 3D CAD rendering and working scale prototype.

5.8. The Scaffolding Mechanism

Students proceed directly to the fabrication lab. To manage structural complexity and mitigate the risks associated with failure, the framework mandates a Low-to-High Fidelity Progression. Students are permitted to use high-value materials or 3D printers only after they have constructed and received approval for a rough, low-fidelity prototype built entirely from cardboard, hot glue, and repurposed wooden dowels. The prototype progression is shown in Figure 6.

5.9. STEAM Integration in Action

This phase prominently features [E] Engineering Fabrication and [T] Digital Technology. Students use computer-aided design (CAD) software to create 3D digital renderings of their designs. They integrate basic hardware components, such as automated microcontrollers, ultrasonic distance sensors, or small solar panels, to add functional utility to their scale models—for instance, by designing a ramp that automatically activates low-voltage LED safety lighting when a user approaches.

Step 5: The Evaluation & Refinement Phase (Weeks 8–9)

PBL Milestone: Public Presentation and Reflection

Embedded DT Phase: Test and Iterate

STEAM Disciplines Engaged: [M] Mathematics and [S] Scientific Inquiry



Figure 7. Testing sequence: user simulation, data collection, and final design optimization.

5.10. The Scaffolding Mechanism

Teams subject their functional prototypes to simulated field tests. To scaffold this evaluation, students employ a structured User Feedback Grid divided into four quadrants: What worked?; What failed?; What questions arose?; and New ideas for improvement. Teams present these iterations to a visiting panel of expert educators, civil engineers, and community members during a final "Public Exhibition of Learning." The testing sequence is shown in Figure 7.

5.11. STEAM Integration in Action

This final phase emphasizes [M] Mathematics and [S] Scientific Inquiry. Students apply mathematical principles to calculate mechanical advantage using a formula such as:

MA = Length of Incline / Height of Rise

They measure load distribution, compute energy efficiency ratios for their solar collectors, and use data-driven analysis to make final structural adjustments to their designs before disseminating their findings.

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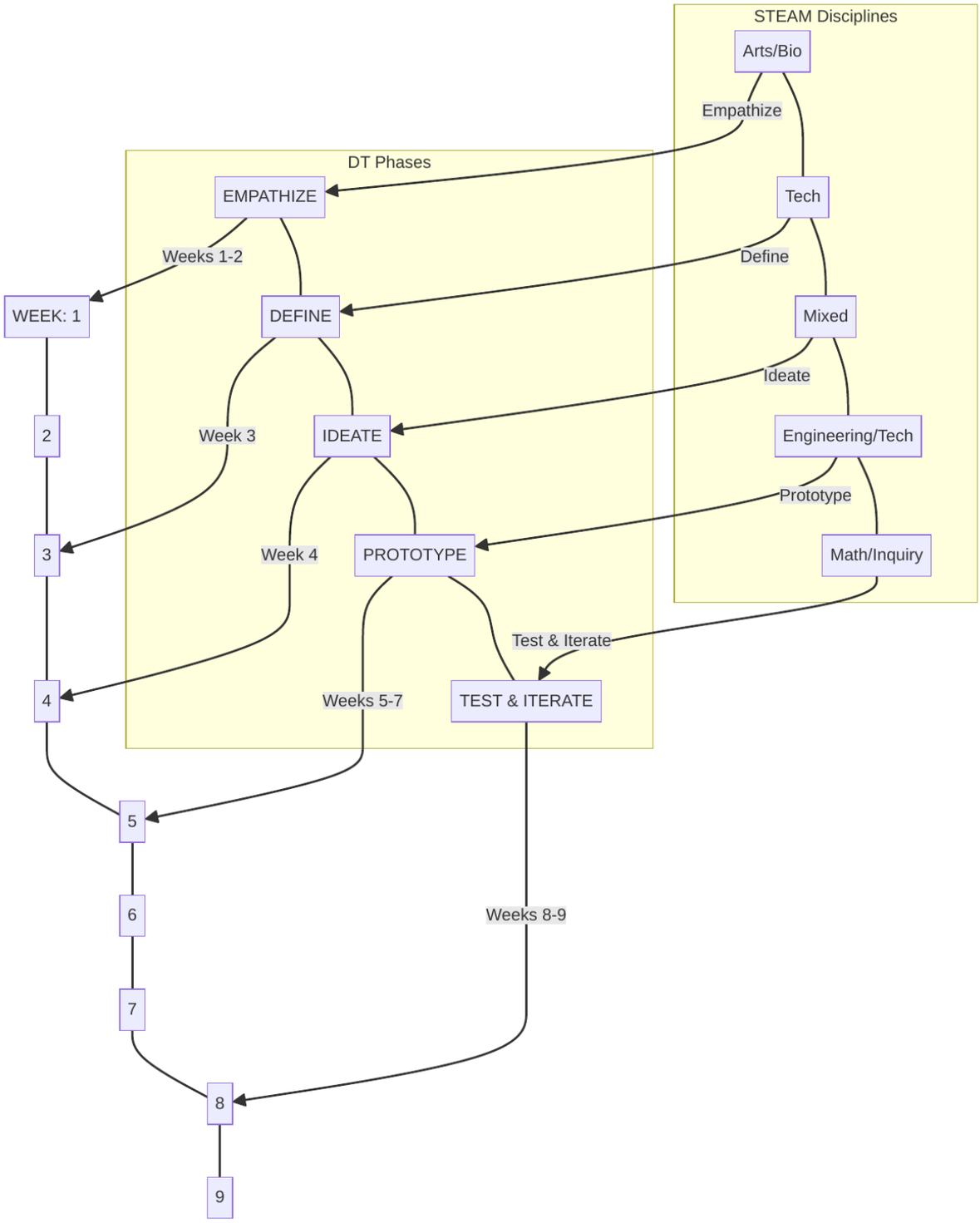


Figure 8. Nine-week project sequence linking Design Thinking phases with project weeks and STEAM disciplines.

6. Results and Data Analysis

This section presents the empirical findings from the nine-week mixed-methods intervention, organized sequentially to address the study's primary research propositions. First, the quantitative data from the pre- and post-tests are presented to establish the statistical significance of shifts in student affect. Second, the qualitative findings are detailed to provide a deeper, contextualized examination of the precise mechanisms that drove those changes.

6.1. Quantitative Findings: Student Affective Shifts

To assess Propositions 1 and 2, paired-samples t-tests were conducted on the pre- and post-intervention scores from the Modified Creative Confidence Scale (MCCS) and the Project-Based Learning Self-Efficacy Survey (PBL-SES).

6.1.1. Statistical Summary Table

Descriptive and inferential statistics for the full cohort (N = 78) are presented in Table 2.

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Table 2. Pre- and post-intervention descriptive and inferential statistics for the full cohort (N = 78).

Instrument	Pre-Test Mean (SD)	Post-Test Mean (SD)	t-value	p-value	Cohen's d	Interpretation
MCCS	3.12 (0.65)	4.28 (0.58)	14.23	<.001	1.11	Large Effect
PBL-SES	2.89 (0.72)	4.15 (0.63)	16.85	<.001	1.23	Large Effect

6.1.2. Statistical Interpretation

Creative Confidence: The paired-samples t-test revealed a statistically significant increase in MCCS scores from pre-test ($M = 3.12$) to post-test ($M = 4.28$), $t(77) = 14.23$, $p < .001$. The calculated Cohen's d was 1.11, indicating that integrating a comprehensive DT model had a very strong practical impact on students' creative confidence.

Learning Self-Efficacy: Analysis of the PBL-SES scores demonstrated an equally significant positive shift, from a pre-test baseline of 2.89 to a post-test mean of 4.15, $t(77) = 16.85$, $p < .001$, $d = 1.23$. This confirms that the highly scaffolded environment protected students from cognitive overload and systematically enhanced their confidence in undertaking open-ended tasks.

6.2. Qualitative Findings: Thematic Analysis

The inductive thematic analysis of focus group transcripts, teacher field notes, and digital process portfolios uncovered three primary themes. These themes elucidate the cognitive and emotional changes captured by the quantitative metrics.

Theme 1: The Metacognitive Re-Framing of Failure (From Deficit to Data)

The qualitative data indicated a significant shift in how middle school students perceived mistakes. Initially, early design failures often led to frustration. However, because the rubric intentionally prioritized and rewarded iteration, students gradually learned to view failure through an objective, analytical lens.

Portfolio Evidence: A typical early entry from Team 3 read: "Our ramp broke when we rolled the weight down it. The wood split. This isn't working and we need to pick a new project." By Week 8, their tone had shifted toward data-driven optimization: "Test 4 failed because the joint angle couldn't handle the stress vector. We are recalculating the rise-to-run ratio and using a stronger composite adhesive for Iteration 5."

Focus Group Insight: One student remarked: "In regular classes, a mistake means you lose points and it's over. Here, the mistake was just the next step. It gave us the exact data we needed to fix the CAD drawing."

Theme 2: Scaffolding as a Cognitive Safe Space

Students explicitly stated that breaking down a vast, open-ended problem into sequential Design Thinking stages prevented them from feeling overwhelmed by the autonomy inherent in Project-Based Learning.

Focus Group Insight: "If the teacher just said 'Go design a sustainable park entrance,' we would have argued for weeks or done something simple. But starting with 'Empathy' gave us a clear goal. We weren't guessing what to do; we were just trying to solve a real problem for the person we interviewed."

Teacher Field Notes: "The 'How Might We' constraint matrix served as an essential anchor. When teams began to drift into unrealistic or overly complicated engineering plans, directing them back to their own written boundaries instantly refocused their attention without requiring micromanagement."

Theme 3: Natural Interdisciplinary Synthesis

Rather than perceiving STEAM as five separate subjects to alternate between, students treated individual disciplines as natural tools for advancing their ideas.

Portfolio Evidence: Student portfolios clearly documented this integrated process. Teams employed mathematical formulas to calculate mechanical advantage, applied material science principles to select sustainable materials, used digital technology to write microcontroller code, and relied on communication arts to present their final design to an audience.

Focus Group Insight: "We didn't say 'Okay, now it's time to do math.' We needed the LED light to turn on exactly when the wheelchair user approached the gate, so we had to figure out the code and use math to calibrate the distance sensor. It just made sense to use it all together."

6.3. Data Convergence: Mixed-Methods Triangulation

Table 3 summarizes how the quantitative indicators correspond to the qualitative themes.

Table 3. Integration of quantitative indicators and qualitative themes.

Quantitative Indicator	Qualitative Explanation
Large MCCS Growth (Cohen's d = 1.11)	Theme 1: Normalizing Failure via Iterative Prototyping
Large PBL-SES Growth (Cohen's d = 1.23)	Theme 2: Process Scaffolding Reducing Cognitive Overload

The substantial, statistically significant quantitative increases in creative confidence and self-efficacy were not coincidental; they were direct outcomes of the design framework's structure. The process scaffolding provided students with a secure cognitive space in which to work, while the iterative prototyping cycles transformed their relationship with failure—enabling them to apply cross-disciplinary STEAM principles to develop sophisticated, real-world solutions.

7. Discussion

The primary objective of this study was to investigate the effects of embedding a highly scaffolded Design Thinking framework within an interdisciplinary STEAM Project-Based Learning environment. The findings offer strong support for both research propositions and demonstrate that structured DT integration can positively influence middle school students' creative confidence and learning self-efficacy. The significant enhancement in creative confidence aligns with prior research indicating that Design Thinking fosters psychologically safe environments for experimentation and innovation [Carroll et al., 2010; Razzouk & Shute, 2012]. Students were

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consistently encouraged to prototype, test, and revise ideas, thereby reducing the perceived risks associated with failure. Instead of viewing mistakes as indicators of incompetence, students increasingly interpreted unsuccessful outcomes as valuable sources of information. Similarly, the substantial growth in learning self-efficacy supports Zimmerman's [2000] assertion that mastery experiences are among the most potent predictors of self-belief. The scaffolded sequence of empathizing, defining, ideating, prototyping, and testing provided manageable cognitive steps that allowed students to experience repeated success throughout the project lifecycle. The qualitative findings further illuminate the underlying mechanisms of these improvements. Students consistently described the Design Thinking stages as "anchors" that reduced uncertainty and provided direction during complex tasks. This observation supports cognitive load theory by suggesting that structured design processes can diminish extraneous cognitive demands, enabling learners to concentrate on meaningful problem-solving. Another notable finding pertains to interdisciplinary knowledge integration. Rather than treating STEAM disciplines as isolated subjects, students naturally combined mathematical reasoning, engineering design, scientific inquiry, artistic communication, and technological tools to address authentic community problems. This suggests that Design Thinking may serve as an effective integrative mechanism for interdisciplinary learning.

Overall, the findings indicate that Design Thinking should not be regarded as an optional enhancement to STEAM-PBL instruction but rather as a central process framework capable of strengthening both cognitive and affective learning outcomes.

7.1. Conclusion

This study provides empirical evidence that an intentionally scaffolded Design Thinking framework can significantly enhance both creative confidence and learning self-efficacy among middle school learners engaged in interdisciplinary STEAM Project-Based Learning. By embedding human-centered inquiry, structured ideation, iterative prototyping, and evidence-based refinement within a cohesive project architecture, the intervention created conditions that supported both cognitive growth and affective development. The findings suggest that Design Thinking functions not merely as a design methodology but as a powerful pedagogical scaffold capable of transforming how students engage with complex real-world challenges. The qualitative themes explain these shifts by demonstrating that process-oriented scaffolding effectively prevents cognitive overload, while iterative prototyping cycles normalize academic failure—converting setbacks from emotional impediments into valuable diagnostic data. By integrating the micro-phases of Design Thinking into the macro-milestones of PBL, this framework successfully elevates middle school STEAM projects from superficial activities to rigorous, human-centered journeys of innovation. Ultimately, this research offers a concrete, tested blueprint for curriculum designers and educational practitioners seeking to cultivate deep metacognitive resilience and genuine interdisciplinary knowledge transfer in young adolescent learners.

7.2. Limitations

While this study offers valuable empirical insights, several limitations must be considered when interpreting the results:

Absence of a Control Group: This study employed a quasi-experimental pre-test/post-test design within a single bounded cohort (N = 78) and lacked a traditional control group. Consequently, history and maturation effects cannot be entirely ruled out as contributing factors to the observed shifts in student affect.

Geographic and Contextual Specificity: The research was conducted at a well-resourced international urban school in Abu Dhabi, United Arab Emirates, with specialized STEAM fabrication laboratories. The resource-intensive nature of this setting may limit the immediate generalizability of the findings to under-resourced public school systems or environments lacking advanced digital fabrication infrastructure.

Reliance on Self-Report Measures: The quantitative metrics relied heavily on self-reported perception scales (MCCS and PBL-SES). Although the self-report data were triangulated with portfolio artifacts and focus group data, self-report instruments can introduce social desirability bias, particularly among middle school students.

Long-Term Sustainability: Although statistically significant gains were observed, the absence of delayed post-testing limits the ability to ascertain the long-term sustainability of the observed improvements in creative confidence and self-efficacy.

7.3. Recommendations for Future Research

Based on the boundaries and insights established by this study, future research should explore the following directions:

Comparative and Longitudinal Research Design: Future studies should implement a randomized controlled trial (RCT) design to directly compare a scaffolded DT-PBL curriculum with a traditional, linear PBL approach. Additionally, tracking these students into high school would reveal whether the observed growth in creative confidence and self-efficacy persists over time. Scalability across Diverse Resource Contexts: Investigating the adaptation of this comprehensive matrix in resource-constrained environments—for example, by using only low-fidelity, recycled prototyping materials without high-tech CAD tools—would test the structural adaptability and equity of the model. Impact on Teacher Self-Efficacy and Pedagogical Shift: Research should shift its focus to educators themselves. Future inquiries should explore the professional development mechanisms, systemic challenges, and structural changes in teacher self-efficacy that occur during the transition from siloed, subject-specific teaching to a co-taught, interdisciplinary DT-PBL matrix.

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