Developing a transdisciplinary design-based in-service science teacher training framework

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ABSTRACT

Contemporary science education requires teachers to facilitate learning that addresses complex, real-world problems beyond disciplinary boundaries. Yet, many in-service science teachers lack professional development that supports transdisciplinary problem-solving and innovative pedagogy. This qualitative study used a grounded theory (GT) approach to examine teachers' experiences in a transdisciplinary, design-based training program and to develop a framework for effective professional learning. Participants engaged in sustained training grounded in design thinking and authentic problem contexts. Data were collected through semi-structured interviews, focus groups, reflective journals, training artifacts, and observations, and analyzed using constant comparative methods. Findings indicated shifts in teachers' conceptions of problem-solving, enhanced capacity to integrate disciplinary and non-disciplinary perspectives, and changes in instructional planning and classroom practice. Design thinking functioned as a mediating process that helped teachers navigate ambiguity, collaboration, and iterative reflection. The resulting transdisciplinary design-based in-service science teacher training framework highlights key principles: authentic problem contexts, structured yet flexible design processes, collaborative inquiry, and iterative reflection. The study offers an empirically grounded framework with implications for teacher professional development, curriculum design, and policy.

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1. INTRODUCTION

Contemporary science education is increasingly shaped by rapid scientific advancement, complex societal challenges, and growing expectations for schools to prepare learners for uncertainty and complexity. Issues such as climate change, public health crises, sustainability, and technological ethics transcend disciplinary boundaries and require ways of thinking that integrate scientific knowledge with social, cultural, and ethical considerations [1], [2]. Globally, science, technology, engineering, and mathematics (STEM) education reforms emphasize 21st-century competencies, problem-solving, and innovation, while national reforms, such as the Philippines' K–12 curriculum and ongoing shifts toward competency-based and contextualized learning, emphasize the need for authentic, inquiry-driven science instruction. These evolving expectations place new demands on science teachers, who must facilitate learning experiences that develop critical thinking, collaboration, and systems-oriented understanding. Consequently, professional development must adapt to support teachers in navigating these expanded roles and reform-driven priorities [3]–[5].

One response to these demands is the growing emphasis on transdisciplinary problem-solving. Unlike multidisciplinary or interdisciplinary approaches, transdisciplinary thinking centers on authentic, complex problems and integrates knowledge from multiple fields alongside non-academic perspectives, such as community knowledge and lived experiences. In reform contexts like the Philippines and other education systems prioritizing STEM competitiveness and contextualized learning, transdisciplinary approaches align closely with policy goals but remain challenging to implement in practice. Many in-service science teachers report limited preparation to design and facilitate such learning experiences effectively. Traditional professional development often remains content-focused, fragmented, and disconnected from classroom realities, offering few sustained, practice-oriented opportunities that support deep pedagogical transformation [6]–[8].

A key challenge is the lack of concrete pedagogical guidance for operationalizing transdisciplinary problem-solving within curriculum and assessment frameworks. Most programs emphasize curricular alignment or assessment compliance rather than equipping teachers to engage learners with complex, real-world problems that connect to community and societal contexts. Design thinking has emerged as a promising approach to address this gap. Rooted in human-centered design, it emphasizes empathy, problem framing, ideation, prototyping, and iterative refinement. These characteristics align with transdisciplinary principles by focusing on ill-defined problems, stakeholder perspectives, and iterative knowledge construction. Design thinking provides a structured yet flexible process that supports teachers in navigating the complexity of reform-oriented science instruction [9], [10].

Despite its theoretical alignment, empirical research examining design thinking integrated into sustained in-service professional development remains limited. Existing studies often focus on pre-service contexts, short-term workshops, or isolated classroom innovations, offering insufficient insight into long-term teacher learning and systemic instructional change. Furthermore, structured frameworks guiding the development, implementation, and refinement of transdisciplinary, design-based training for practicing teachers, particularly within national reform environments, are largely absent. Few studies have examined sustained, design-based transdisciplinary training programs specifically for in-service science teachers or generated empirically grounded models to guide systematic implementation. This gap highlights the need for research that situates teacher learning within authentic reform contexts while generating actionable design principles for future programs [11]–[15].

The novelty of this study lies in integrating design thinking within a transdisciplinary professional development framework for in-service science teachers using a design-based research approach. It emphasizes iterative refinement grounded in participant experiences and contextual demands. Unlike prior research treating transdisciplinary learning or design thinking in isolation, this study positions design thinking as both a pedagogical scaffold and analytical lens for examining professional learning in reform-driven settings. It focuses on sustained engagement, capturing how teachers' conceptions of problem-solving and instructional practice evolve over time. By linking insights from grounded theory (GT) with practical implementation, the study provides a coherent model for preparing teachers to address complex, authentic problems aligned with national and global STEM priorities.

Specifically, the study investigates: i) how in-service science teachers experience a transdisciplinary, design-based professional development program; ii) how participation influences their conceptions of science teaching and problem-solving within reform contexts; and iii) what actionable design principles emerge from implementing the framework. By foregrounding teachers' lived experiences in authentic contexts, the study contributes theoretically by extending understanding of transdisciplinary competencies and practically by offering a replicable, context-sensitive framework supporting sustained professional growth [16]–[19]. The findings aim to guide teacher educators, curriculum developers, and policymakers seeking sustainable, responsive professional development aligned with national curriculum reforms and global STEM priorities.

2. METHOD

2.1. Research design

This study employed a qualitative approach grounded theory to explore how in-service science teachers developed transdisciplinary understandings [20]. While participants participated in a design-based professional development program featuring iterative design-thinking activities, these activities served solely as the context for data collection and did not determine the analytical process. Data—including reflections, discussions, lesson artifacts, and interviews—were analyzed inductively following GT procedures: open coding, constant comparison, memo writing, and theoretical sampling. Importantly, theoretical categories emerged from the data itself rather than being imposed by the design-thinking framework; connections to the professional development activities were considered only after categories were fully developed. In this way, the study maintains a clear GT focus, with the design-based program providing a rich empirical setting without predetermining analytical outcomes, ensuring methodological clarity and conceptual rigor [21].

2.2. Participants and research context

Participants were 25 purposively selected secondary science teachers with 2–20 years of experience, teaching grades 7–12 across urban and suburban contexts. All were recruited at the outset based on engagement in collaborative professional development and availability throughout the program. Theoretical sampling was implemented iteratively during data collection and analysis. Although all participants were initially included, subsequent interviews, lesson artifacts, and focused reflections were selectively gathered from individuals whose experiences could further elaborate or challenge emerging categories [22]. Data saturation was determined when additional sampling and coding no longer produced new properties, dimensions, or relationships within the categories. The study was conducted in authentic professional settings through workshops and blended sessions that supported collaboration, reflection, and classroom application, with contextual factors such as time, curriculum, and technology documented to enhance interpretive transferability.

2.3. Training intervention

The training intervention aimed to develop 25 secondary science teachers' transdisciplinary problem-solving skills using the design thinking framework: empathize, define, ideate, prototype, and test. Conducted over 40 hours or five days, the program targeted teachers of high school sciences, representing diverse teaching experience and school contexts. Learning outcomes included reflective practice, integration of disciplinary and societal perspectives, and design of instructional activities grounded in authentic problems. The program incorporated collaborative exercises, problem-based scenarios (e.g., environmental sustainability, community science), and iterative refinement based on participant feedback. This adaptive structure enabled alignment with emerging GT categories, promoting practical application of transdisciplinary and design thinking principles while providing transparent information to support interpretive transferability [23].

2.4. Data collection

Multiple qualitative methods were employed to capture teachers' experiences comprehensively. Semi-structured interviews were conducted before, during, and after the program to record evolving perspectives. Focus group discussions facilitated collaborative meaning-making, while reflective journals documented ongoing insights. Training artifacts, including lesson plans and prototypes, provided evidence of applied learning, and field observations captured engagement and interactions. The triangulation of these sources enhanced the credibility and robustness of emerging categories [24].

2.5. Data analysis, trustworthiness, and ethics

Data were analyzed using the constant comparative method. During open coding, meaningful segments from participants' reflections, discussions, interviews, and lesson artifacts were labeled with initial codes such as "collaboration in lesson planning," "problem-solving strategies," and "classroom application of design-thinking." Axial coding then grouped these codes into broader categories, for example, "integrative teaching approaches," "iterative design engagement," and "transdisciplinary thinking." Selective coding integrated these categories around the core category of "transdisciplinary professional learning development," which anchors the emerging GT [25]. Analytic memos documented coding decisions, category formation, and evolving theoretical insights, providing a clear audit trail of how raw data progressed to initial codes, categories, and the core category. Rigor was ensured through prolonged engagement, triangulation of data sources, audit trails, peer debriefing, and reflective memoing, enhancing credibility, dependability, confirmability, and transferability. Ethical standards were strictly followed: the study received institutional approval, all participants provided informed consent, confidentiality was maintained through pseudonyms and secure data storage, and participants could withdraw at any time, ensuring a respectful environment for reflective professional learning.

3. RESULTS

3.1. Teachers' conceptions of transdisciplinary problem-solving

At the outset of the training, participants exhibited limited familiarity with transdisciplinary problem-solving. Most teachers associated problem-solving primarily with scientific reasoning within their own subject area. As one participant noted:

> "*I usually think of problem-solving as applying formulas or experiments from my subject… I didn't consider social or ethical dimensions before.*" (Teacher A)

Initial conceptions were largely disciplinary and teacher-centered, focusing on content delivery rather than integration across domains. However, as the training progressed, teachers reported shifts in their perspectives. Exposure to real-world, cross-disciplinary problems encouraged them to view knowledge as interconnected and contextually applied. One teacher reflected:

> "*Working on the environmental project made me realize that science doesn't exist in a vacuum; students need to think about social impact, ethics, and practical solutions, not just the theory.*" (Teacher L)

These shifts showed a growing appreciation for the complexity of transdisciplinary problem-solving. Iterative engagement with authentic problems supported both cognitive and pedagogical growth. This suggests that hands-on, real-world tasks can foster deeper learning.

3.2. Experiences with design thinking in training

Participants described the benefits of using design thinking as a structured approach to tackle complex problems. They highlighted its potential to foster creativity, collaboration, and reflective practice. One teacher stated:

> "*The ideation and prototyping stages really helped me see multiple ways to approach a problem and not just settle on the first idea.*" (Teacher C)

Teachers also valued the human-centered focus, noting that empathizing with stakeholders, including students and community members, improved their problem framing. Nonetheless, participants reported challenges. Some found the iterative cycles initially overwhelming, while others struggled with time management and uncertainty inherent in open-ended tasks:

> "*I kept thinking, 'Am I doing this right?' The ambiguity was uncomfortable at first, but gradually I saw the value of trying and revising ideas.*" (Teacher F)

These experiences show that design thinking can be empowering. Its effectiveness depends on supportive facilitation, reflection, and iterative engagement. Without these, professional development outcomes may be limited.

3.3. Professional learning and practice implications

The training had a clear impact on teachers' professional learning, particularly regarding instructional planning and classroom practice. Many participants reported integrating transdisciplinary problem-solving principles into lesson design, creating activities that connected science with societal, ethical, and environmental contexts. For example, one teacher explained:

> "*I redesigned my chemistry unit to include a local water quality issue. Students now had to analyze data, propose solutions, and discuss social implications—it made the learning much more meaningful.*" (Teacher D)

Teachers reflected on a shift from teacher-centered instruction to facilitating student-centered, inquiry-based learning. They highlighted improved collaboration among colleagues. They also emphasized using iterative assessment and feedback to support student problem-solving.

3.4. Emergent design principles

Analysis of participant experiences and artifacts led to the identification of key features of effective transdisciplinary training. First, real-world problem contexts were essential to making learning relevant and motivating. Second, structured yet flexible design thinking processes facilitated iterative reflection, creativity, and solution development. Third, collaborative engagement promoted peer learning and co-construction of knowledge.

Participants suggested refinements to the framework, such as clearer scaffolding for early design-thinking stages. They recommended more time for iterative prototyping and ongoing classroom support. One teacher remarked:

> "*I think the framework works best when we have clear examples and checkpoints along the way; it's easier to connect theory to practice.*" (Teacher G)

These insights guided the refinement of the training framework. They highlighted the need for contextualized scaffolds, reflective cycles, and adaptive support. Such elements are key to sustaining teacher learning and transdisciplinary application. Overall, the findings indicate that in-service science teachers can develop robust transdisciplinary problem-solving capacities when supported by design thinking–based professional development. Teachers experienced cognitive and pedagogical shifts, reported tangible changes in instructional practice, and contributed to the refinement of a practical framework for transdisciplinary, design-oriented training. Key principles emerging from the study guide structuring future professional development programs, emphasizing iterative design, authentic problem contexts, collaborative learning, and reflective engagement.

4. DISCUSSION

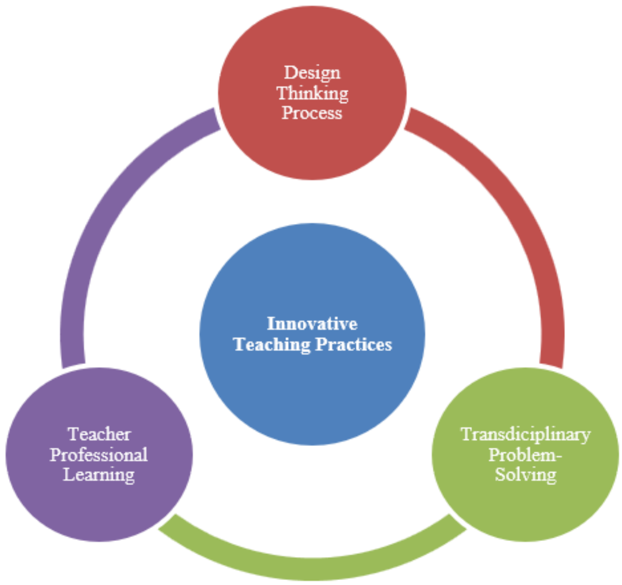
This study investigated the development and implementation of a transdisciplinary design-based in-service science teacher training framework to examine how in-service science teachers engage in transdisciplinary problem-solving through design thinking and how this shapes professional learning. Initially, teachers approached problems through disciplinary, content-centered lenses, emphasizing procedural strategies and established routines. Sustained engagement with authentic, complex problems shifted their thinking toward integrative approaches, recognizing links among scientific knowledge, social contexts, and ethical considerations. Design thinking provided a structured yet flexible scaffold that supported navigation of ambiguity, fostering creativity, collaboration, and reflective practice. While participants initially experienced discomfort with uncertainty and time demands, iterative cycles of ideation, prototyping, and testing facilitated deeper engagement and meaningful learning. The training influenced professional practice, shaping instructional planning, curriculum design, and classroom implementation toward student-centered, collaborative, and contextually relevant science learning. Four emergent design principles were identified: grounding learning in authentic problem contexts, employing iterative design-thinking cycles, fostering collaborative inquiry, and embedding reflection and feedback.

These shifts in teachers' conceptions of problem-solving illustrate not only practical growth but also extend existing understandings of transdisciplinary learning and teacher professional development. While prior research emphasizes that teachers often rely on disciplinary approaches when facing new pedagogical demands, this study shows how engagement with authentic, transdisciplinary problems can actively reshape epistemological and pedagogical orientations. By integrating multiple knowledge domains, negotiating societal and ethical considerations, and collaborating with peers, teachers demonstrated the co-construction of knowledge in ways that refine theoretical models of transdisciplinary learning. Design thinking acted as both a cognitive and pedagogical scaffold: its structured phases supported management of complexity, and its iterative nature promoted experimentation, reflection, and risk-taking. The observed tensions with ambiguity further highlight the theoretical importance of scaffolding and guided facilitation in transdisciplinary professional learning. Finally, the application of new strategies in classrooms—connecting scientific concepts to real-world issues—reinforces and extends constructivist and sociocultural perspectives, demonstrating how transdisciplinary teacher development can simultaneously advance pedagogical practice and theoretical understanding of learning in authentic, complex contexts.

Within the broader literature, these findings are consistent with and extend prior research on transdisciplinary learning and design thinking in science education. While earlier studies emphasize benefits for student learning, this study demonstrates that teachers benefit from engaging in transdisciplinary inquiry, developing competencies that inform classroom practice [1], [6], [10], [15], [19]. The use of design thinking aligns with literature highlighting its role in promoting reflective, collaborative, and innovative professional learning. This study extends prior work by integrating design thinking and transdisciplinary problem-solving into a coherent, sustained framework for in-service teacher training. Challenges reported by participants, including discomfort with ambiguity and time constraints, mirror earlier findings, reinforcing the need for scaffolded support and iterative implementation. Unlike short-term interventions, this study demonstrates the value of sustained engagement, contributing practical design principles addressing gaps in operational models for transdisciplinary professional development [3], [9], [14], [17].

These findings carry important implications for science education and teacher professional development. Professional learning initiatives should move beyond content transmission models to engage teachers with authentic, complex problems requiring integration of disciplinary knowledge with societal and ethical considerations, fostering epistemological flexibility and pedagogical innovation. The structured use of design thinking offers a practical scaffold for supporting teachers as they navigate complexity and uncertainty, guiding participants through iterative cycles of problem framing, ideation, prototyping, and evaluation while promoting collaboration and reflection. Embedding opportunities for peer feedback and refinement is essential for sustaining engagement and deepening professional learning.

Building on these implications, the study proposes a transdisciplinary design-based in-service science teacher training framework integrating transdisciplinary problem contexts, design thinking processes, and teacher professional learning within an iterative cycle. Authentic real-world problems anchor inquiry, while design thinking processes provide structured yet flexible pathways for creative exploration and reflection. Outcomes include enhanced professional learning, shifts in pedagogical practice, strengthened problem-solving capacities, and innovative curriculum design, emphasizing continuous reflection, refinement, and knowledge co-construction, as presented in Figure 1.



Notes:
- Center: innovative teaching practices — teachers apply design thinking, transdisciplinary problem-solving, and reflective professional learning to create engaging, real-world learning experiences.
- Center (top): design thinking process—stages of empathize, define, ideate, prototype, and test, providing a structured approach for teachers to engage with problems creatively and iteratively.
- Left: teacher professional learning—shifts in pedagogical practice, problem-solving capacities, reflective engagement, and curriculum design.
- Right: transdisciplinary problem-solving—collaboratively apply knowledge from multiple disciplines to solve complex real-world problems.

Figure 1. Transdisciplinary design-based in-service science teachers' training framework

To implement this framework, an action-oriented approach involves problem identification, challenge framing, ideation, prototyping, classroom implementation, reflection, and refinement. Key considerations include selecting locally relevant problems, scaffolding interdisciplinary integration, and facilitating collaborative inquiry. Iterative testing enables teachers to adapt innovations while building professional confidence. Beyond its practical application, the study extends theories of transdisciplinary learning and teacher professional development by showing how sustained, design-based engagement fosters integrated problem-solving, reflective pedagogy, and adaptive expertise. This demonstrates that transdisciplinary, design-based professional development can both theoretically and practically enhance teachers' capacity to navigate complex, real-world problems, offering a model that bridges conceptual understanding and classroom practice, as shown in Table 1.

Table 1. Proposed action plan

Phase/action	Key activities	Considerations
1. Problem Identification	Select authentic, real-world issues relevant to local context; involve stakeholders (students, community, experts)	Ensure problems are complex, interdisciplinary, and socially relevant; align with curricular objectives
2. Empathize/needs assessment	Conduct teacher and learner needs analysis; explore existing practices and challenges	Use surveys, interviews, focus groups; identify teacher knowledge gaps and classroom constraints
3. Define/framing challenges	Guide teachers to articulate problem statements; highlight interdisciplinary dimensions	Provide scaffolds for clarifying scope; emphasize ethical, societal, and environmental considerations
4. Ideate/solution generation	Facilitate collaborative brainstorming; develop multiple instructional strategies or lesson prototypes	Encourage creativity; document ideas; balance feasibility with innovation
5. Prototype/lesson design	Develop lesson plans, activities, or interventions integrating multiple disciplines	Include materials, resources, and assessment criteria; consider classroom logistics
6. Test/implementation	Pilot lessons in classrooms; gather feedback from teachers and students	Monitor engagement and learning outcomes; encourage teacher reflection and peer observation
7. Reflect/iterative review	Conduct reflective sessions; analyze successes, challenges, and areas for improvement	Use journals, focus groups, and artifacts; identify patterns for framework refinement
8. Refine/scaling	Adjust training modules, design principles, and support mechanisms based on feedback	Ensure adaptability for diverse contexts; integrate ongoing support and professional learning communities

5. CONCLUSION

This study shows that transdisciplinary, design-based professional development can meaningfully transform in-service science teachers' problem-solving and instructional practices. Engagement with authentic, complex problems via design thinking shifted teachers from disciplinary, content-centered approaches to integrative, student-centered practices connecting scientific, social, and ethical knowledge. Structured facilitation, iterative cycles, and reflective opportunities supported teachers in navigating ambiguity and applying new insights, resulting in redesigned lessons, increased collaboration, and more inquiry-based instruction. Four emergent design principles: authentic problem contexts, iterative design-thinking cycles, collaborative inquiry, and embedded reflection, provide practical guidance for teacher educators and curriculum developers and advance theoretical understanding of transdisciplinary science education. Future research could explore the framework's long-term sustainability and scalability, using mixed-methods, longitudinal, or cross-context studies to examine its impact on adaptive teaching across diverse educational settings.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY

The qualitative data generated in this study, including interviews, reflective journals, and lesson artifacts, were collected as part of the research process and are not publicly available to protect participants' confidentiality. De-identified data may be made available upon reasonable request to the corresponding author, subject to ethical approval and the establishment of appropriate data sharing agreements.

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