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Development of a Learning Innovation Competency Enhancing Program for Science Teachers Based on the Engineering Design Approach

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Abstract

This study developed a professional development program to enhance science teachers' learning innovation competency through an engineering design approach. Guided by a research and development framework, the study was conducted in two phases. Phase 1 synthesized a competency framework from related literature, resulting in four sub-competencies—Preparing, Creating, Implementing, and Assessing—with 15 behavioral indicators. The framework and related instruments were validated by five experts, and all indicators met the acceptable criterion for content validity. Phase 2 translated the framework into a professional development program consisting of eight engineering design steps and six training modules. The draft program was evaluated by experts, rated at a high to very high level of appropriateness, and piloted with 14 science and technology teachers in an authentic school setting. Data from participant reflections, observer records, self-assessment, and satisfaction ratings informed program refinement. The findings indicate that the program was conceptually sound, contextually relevant, and operationally feasible, while also highlighting the need to improve activity sequencing, reflection structure, competency-activity-assessment alignment, and evidence-based evaluation criteria. This study contributes both a validated competency framework and a systematically refined professional development program for science teachers. Future research should examine the effectiveness of the program in full-scale implementation.

Keywords: science teachers, learning innovation competency, professional development, engineering design approach, research and development

1. Introduction

Innovation involves transforming knowledge, skills, experience, and creativity into new products, services, or processes that create economic and social value. In the twenty-first century, innovation has become increasingly central to national competitiveness and development (Ovbiagbonhia et al., 2019; Hallström et al., 2023). In response, Thailand has sought to move toward a value- and innovation-driven economy by strengthening human capacity in research and innovation through education to enhance national competitiveness (Rukspollmuang & Fry, 2022; Dutta et al., 2021).

In education, science plays an important role in developing learners' logical reasoning, systematic thinking, and evidence-based decision making (NRC, 2012; García-Carmona, 2025). Accordingly, science education should go beyond content acquisition to foster conceptual understanding, inquiry, questioning, evidence-based explanation, and the application of knowledge to real-world problems (NRC, 2000, 2012). Achieving these goals requires not only strong curriculum content but also learning approaches that foster curiosity, support inquiry, and actively engage students in scientific practices (NRC, 2000, 2012; Kang & Kim, 2024). In this study, learning innovation refers to the design and development of instructional approaches that are new or substantially adapted to address learning problems, including instructional units, lesson plans, learning activities, materials, assessment tools, and classroom management processes that are evidence-informed and continuously improved (Richey et al., 2011).

Despite these expectations, science instruction in many classrooms remains dominated by teacher-centered and lecture-based approaches (Stains et al., 2018). As a result, students often have limited opportunities to participate

actively, engage in hands-on inquiry, ask questions, and develop problem-solving and science process skills (Chin, 2007; Minner et al., 2010). Under these conditions, students may be less likely to develop deep conceptual understanding or apply scientific knowledge meaningfully in new situations (Furtak et al., 2012; Minner et al., 2010). One contributing factor is that teachers often have limited preparation time and insufficiently sustained professional development, which makes the implementation of active and innovation-oriented instruction difficult in practice (NRC, 2000; Mizell, 2010). Prior research also suggests that meaningful teacher learning is more likely when professional development is sustained, practice-based, and designed with strong features such as content focus, active learning, coherence, and ongoing support (Desimone, 2009; Guskey, 2000; Darling-Hammond et al., 2017).

Because teachers are central to improving student learning, strengthening their competence in designing and implementing learning innovations remains a critical challenge for education systems. When teachers lack the knowledge, understanding, and dispositions required for learner-centered instruction, they may perceive innovation development as difficult and impractical, thereby hindering meaningful instructional change (van Driel et al., 2001; Crawford, 2007; Marco-Bujosa et al., 2017). Therefore, schools and related agencies need teacher development systems that enable science teachers to identify learning problems, design and implement innovations systematically, and evaluate and refine those innovations based on evidence (Richey et al., 2011). However, although workshops and professional development activities are widely implemented, many programs still do not provide a sufficiently systematic process that helps teachers develop innovation competency across the full cycle of practice, from problem identification and evidence gathering to prototype development, classroom implementation, feedback collection, and continuous refinement (Desimone, 2009; Guskey, 2000; Loucks-Horsley et al., 2010; Maneelam, 2022; Wansomsakul et al., 2023).

One promising response is the development of a professional development program for science teachers grounded in a systematic conceptual framework. Such programs typically include needs analysis, planning, learning activities, evaluation, and reporting, while allowing collaboration and adaptation to local contexts (Porter & Schroeder, 1980; Boyle, 1981; Boone, 1992; Rogers, 2000; Wongwanich, 2001; Loucks-Horsley et al., 2010; Mizell, 2010). If such a program is intended to strengthen science teachers' learning innovation competency, it should engage teachers in a systematic design and development process that includes problem analysis, information gathering, prototype development, pilot testing, evaluation, and iterative refinement (Richey et al., 2011; McKenney & Reeves, 2018; Design-Based Research Collective, 2003).

The engineering design approach offers a suitable framework for this purpose. As a systematic problem-solving process, engineering design emphasizes designing, testing, evaluating, and improving products or processes in response to user needs (Dym et al., 2005; NRC, 2012; National STEM Education Center, 2016). In teacher professional development, this approach can support science teachers in analyzing instructional problems, using evidence to inform pedagogical decisions, and designing creative and practical solutions through iterative development and collaboration (Brand, 2020; Christian et al., 2021; McFadden & Roehrig, 2017). It may also strengthen how teachers articulate, justify, and refine instructional decisions during practice (Brand, 2020; Christian et al., 2021).

Existing studies on engineering design in education have focused mainly on students or pre-service teachers. In contrast, program-based development aimed at enhancing the learning innovation competency of in-service science teachers remains limited, particularly in Thailand, where many related studies have emphasized student-level applications or pre-service teacher learning rather than systematic teacher development programs for in-service science teachers (Widiastuti et al., 2020; Shahat et al., 2022; Shahat et al., 2024; Puchongprawet, 2023; Koocharoenpisal, 2023; Manopattanakron et al., 2024). This gap highlights the need for a professional development program specifically designed for in-service science teachers that can be implemented in authentic classroom settings and that supports innovation-oriented science teaching in a concrete and systematic manner.

Accordingly, this study developed a program to enhance science teachers' learning innovation competency through an engineering design approach. The study focuses on the development process, structure, and format of the program, together with expert review and reflective evidence from pilot refinement. The evaluation of program effectiveness in terms of outcome variables is beyond the scope of this article and will be addressed in a subsequent phase of the research.

1.1 Objectives

This study aimed to synthesize the components and conceptual framework of science teachers' learning innovation competency; and develop a program to enhance science teachers' learning innovation competency through an engineering design approach.

2. Method

This study employed a research and development (R&D) approach to (1) synthesize the components and conceptual framework of science teachers' learning innovation competency and (2) develop a program to enhance such competency through an engineering design approach. The study integrated document analysis, expert validation, program design, and pilot refinement, using both quantitative and qualitative data. This article focuses on the development and quality validation of the conceptual framework, instruments, and program format rather than on statistical testing of program effectiveness, which will be examined in a subsequent phase (Richey et al., 2011; Desimone, 2009; Guskey, 2000; Darling-Hammond et al., 2017). The study comprised two phases: Phase 1, foundational study and conceptual synthesis, and Phase 2, program development and refinement.

2.1 Phase 1: Foundational Study and Conceptual Synthesis

Phase 1 examined three areas: (1) science teachers' learning innovation competency, (2) the engineering design process, and (3) principles of teacher professional development program design. Relevant books, policy documents, academic texts, peer-reviewed journal articles, theses, and prior empirical studies related to science teacher development, learning innovation, engineering design, and teacher professional development were purposively reviewed and synthesized to construct the competency framework and identify process-oriented concepts appropriate for the Thai educational context. Source selection was guided by relevance to the objectives of the study, conceptual significance to the target constructs, and applicability to science teaching and teacher development. Both Thai and international sources were included in order to ensure conceptual breadth and contextual relevance. The document review followed a conceptual comparison and categorization process. First, the selected sources were read repeatedly to identify key ideas, recurring themes, and important conceptual elements related to teacher innovation competency and engineering design. Second, the extracted concepts were compared across sources and grouped into preliminary categories. Third, these categories were synthesized into broader conceptual dimensions and then translated into draft sub-competencies, behavioral indicators, and engineering design principles. This synthesis was guided by recognized features of effective professional development, including content focus, active learning, coherence, and sustained support (Desimone, 2009; Darling-Hammond et al., 2017). Based on this synthesis, the researcher developed the research framework showing the relationships among learning innovation competency, the engineering design process, and the structure of the professional development program. Draft definitions, competency components, behavioral indicators, and related instruments were then submitted to five experts for content validation. The experts were selected purposively to represent complementary areas of expertise relevant to the study, including science teaching practice, science education, curriculum and instruction, and measurement and evaluation. This expert composition was intended to strengthen the conceptual appropriateness, contextual relevance, and evaluative rigor of the synthesized framework. The experts rated each item as +1, 0, or -1, and the Index of Item-Objective Congruence (IOC) was calculated to determine the degree of congruence between each item and the intended construct. In addition, their qualitative comments were analyzed and used to refine the wording, conceptual clarity, behavioral specificity, and practical applicability of the framework and related instruments before they were used in the next phase of the study.

2.2 Phase 2: Program Development and Refinement

Phase 2 focused on developing and refining the program. Findings from Phase 1 informed the design of the program's principles, objectives, structure, sequence, and activities. The program design integrated the teacher development framework proposed by Loucks-Horsley et al. (2010) with the synthesized engineering design process and was further informed by evidence-based characteristics of effective professional development, including active learning, coherence with authentic teaching practice, and ongoing support (Desimone, 2009; Guskey, 2000; Darling-Hammond et al., 2017). The output of this stage was a draft prototype including its modules, activities, duration, materials, and evaluation guidelines. Supporting documents consisted of a program manual and sample training plans.

The draft program and supporting documents were reviewed by five purposively selected experts with experience in teacher professional development, science teachers' learning innovation competency, or science and engineering practices. The expert panel was intentionally composed to cover both practical and academic perspectives relevant to the study. Two instruments were used: an IOC form to evaluate the alignment of program components and a program quality and appropriateness assessment form with 5-point rating-scale items and open-ended questions. Quantitative and qualitative feedback was used to revise the draft program before pilot implementation.

Two participant groups were involved in the study: five experts and 14 science and technology teachers from one school who participated in the pilot refinement phase. The pilot participants were purposively selected because they represented the intended target users and could provide contextually relevant feedback on implementation feasibility, activity clarity, and practical usability. Three observers also participated in the pilot phase to record the flow of activities, participant behaviors, implementation issues, and the extent to which intended outcomes appeared during training.

The pilot refinement phase lasted three days and covered three modules: Module 1, *Discovering Problems for Innovation*; Module 3, *Igniting Creative Ideas for Solutions*; and Module 4, *Planning and Designing Functional Innovations*. These modules were selected because they represented core upstream stages of innovation development and were appropriate for examining the clarity of instructions, continuity of the learning sequence, and alignment between activities and target competencies. Data from participants and observers were used to assess operational feasibility, activity coherence, and the usability of support tools, and were then used to refine the sequence of activities, module descriptions, support tools, and procedural structure of the program.

2.3 Research Instruments

The study used three groups of instruments. First, expert validation instruments included an IOC form for evaluating the congruence of framework and program items with their objectives and content, and a program quality and appropriateness assessment form with 5-point rating-scale items and open-ended questions. Second, participant-based pilot instruments included module activity logs, a 15-item self-assessment of learning innovation competency covering four domains (Preparing, Creating, Implementing, and Assessing), and a 15-item satisfaction questionnaire. Third, three observers completed descriptive observation records during the pilot implementation. These instruments were used together to capture both evaluative judgments and implementation-related evidence from multiple perspectives.

2.4 Data Collection Procedures

Data collection was conducted in two phases. In Phase 1, the competency framework and related instruments were submitted to five experts for content validation, and their quantitative ratings and qualitative comments were used to revise the framework and instruments. In Phase 2, the draft program and supporting documents were submitted to the expert panel for evaluation of program quality and appropriateness, and the resulting feedback was used to revise the program before pilot implementation. The pilot refinement phase was then conducted with 14 science and technology teachers across three modules over three days. During the pilot, data were collected from module activity logs, self-assessment forms, satisfaction questionnaires, and observer records to identify strengths, implementation issues, and areas requiring refinement. Data collection in the pilot phase was intended primarily to support program refinement rather than to determine program effectiveness.

2.5 Data Analysis

Both quantitative and qualitative data analysis procedures were employed. Quantitative data from expert validation were analyzed using IOC, with values of 0.80 or above considered acceptable. Quantitative data from expert program evaluation, participant self-assessment, and the satisfaction questionnaire were analyzed using descriptive statistics, including mean, standard deviation, and, where appropriate, median and interquartile range. Where item-level data were available, internal consistency reliability of the self-assessment and satisfaction instruments was examined using Cronbach's alpha. Qualitative data from expert comments, participant activity logs, and observer records were analyzed using directed content analysis. Initial coding categories were derived from the conceptual framework and the program design focus of the study, including conceptual clarity, competency-activity alignment, implementation feasibility, participant engagement, activity flow, and suggestions for program refinement. Data were read repeatedly, coded according to these initial categories, compared across sources, and synthesized into recommendations for revising the final version of the program. When relevant data did not fit the preliminary coding frame, additional subcategories were created to better reflect the empirical evidence. Trustworthiness was strengthened through triangulation across expert reviews, participant reflections, and observer notes.

2.6 Ethical Considerations

This study was approved by the Human Research Ethics Committee of Mahasarakham University (Approval No. 811-637/2568). All participants were informed about the study objectives, procedures, and their rights as participants. Participation was voluntary, withdrawal was allowed at any time without consequences, and all data were kept confidential and reported only in aggregate form for academic purposes.

3. Results

3.1 Phase 1: Foundational Study and Conceptual Synthesis

3.1.1 Synthesis of Science Teachers' Learning Innovation Competency

Phase 1 showed that science teachers' learning innovation competency refers to the ability to integrate knowledge, skills, and dispositions to create or adapt science learning innovations that fit classroom contexts and learning goals. These innovations may involve newly created instructional solutions or the adaptation of existing methods, ideas, or tools to improve science teaching and learning.

The synthesis yielded a competency framework comprising four sub-competencies and 15 behavioral indicators, representing a systematic innovation process from preparation to implementation, evaluation, and improvement (Table 1).

Table 1. Synthesized Structure of Science Teachers' Learning Innovation Competency

Sub-competency	Description	Behavioral Indicators
Preparing	Foundational capacity for understanding learners, analyzing contextual needs, and defining goals for innovation development.	1.1 Understanding target learners and identifying their needs; 1.2 Defining problems and objectives for innovation development 1.3 Reviewing documents and examining concepts, theories, or principles that support innovation development 1.4 Understanding the fundamental principles of learning innovation.
Creating	Capacity to initiate, design, and collaboratively develop learning innovations that differ from previous instructional practices.	2.1 Generating creative and novel ideas for learning innovation 2.2 Designing and developing innovation prototypes 2.3 Planning innovation development 2.4 Coordinating and collaborating with others to support innovation development.
Implementing	Capacity to plan, manage, and examine the use of learning innovation in actual classroom practice.	3.1 Determining how the learning innovation will be implemented 3.2 Planning the management of implementation 3.3 Examining the feasibility and preliminary effectiveness of the learning innovation Summarizing the results of pilot implementation.
Assessing	Capacity to evaluate, report, and improve learning innovation through evidence-informed reflection and revision.	4.1 Determining methods for assessing and monitoring the development and implementation of learning innovation 4.2 Reporting and disseminating learning innovation 4.3 Improving and refining learning innovation based on evaluation results and feedback.

Preparing refers to the foundational capacity needed before innovation development. It includes understanding learners and their needs, defining problems and objectives, reviewing supporting concepts and theories, and understanding the principles of learning innovation. This domain emphasizes contextual awareness and academic grounding before development begins.

Creating refers to the ability to generate, design, and develop learning innovations. Its indicators include generating creative ideas, designing prototypes, planning development, and collaborating with others. This domain highlights the transformation of ideas into concrete instructional innovations.

Implementing connects innovation design to classroom use. It includes determining implementation approaches, planning implementation management, examining feasibility and preliminary effectiveness, and summarizing pilot results. This domain reflects teachers' professional judgment in adapting innovations to real classroom conditions.

Assessing supports continuous improvement. It includes determining assessment and monitoring methods, reporting and disseminating innovation, and refining innovation based on evidence and feedback. This domain emphasizes evidence-informed reflection and revision.

The synthesis also indicated that competency assessment should be grounded in authentic classroom situations. Three complementary forms of assessment were therefore identified for later stages of the study: observation by facilitators and observers, teacher self-assessment, and structured qualitative interviews. Across these instruments, the same 15 indicators were used under the four sub-competencies, with five performance levels reflecting developmental progression. In this article, these instruments are reported primarily to demonstrate the clarity and appropriateness of the competency indicators rather than to claim program effectiveness.

3.1.2 Synthesis of Engineering Design Principles

The document review indicated that the engineering design approach can be understood as a process-oriented framework combining systematic reasoning and creativity to solve problems and develop solutions that respond

to user needs under real-world constraints. Key characteristics include defining problems clearly, using resources efficiently, considering safety and risk, and working collaboratively across expertise (Figure 1).

From this synthesis, seven principles were identified as the conceptual foundation for program development: (1) systematic problem analysis, (2) creativity and innovation, (3) efficient use of resources, (4) iteration and flexibility, (5) feasibility and usability, (6) safety and risk management, and (7) collaboration across expertise.

Together, these principles provided a systematic and context-responsive basis for translating the engineering design approach into program principles and structuring the next stage of program development.

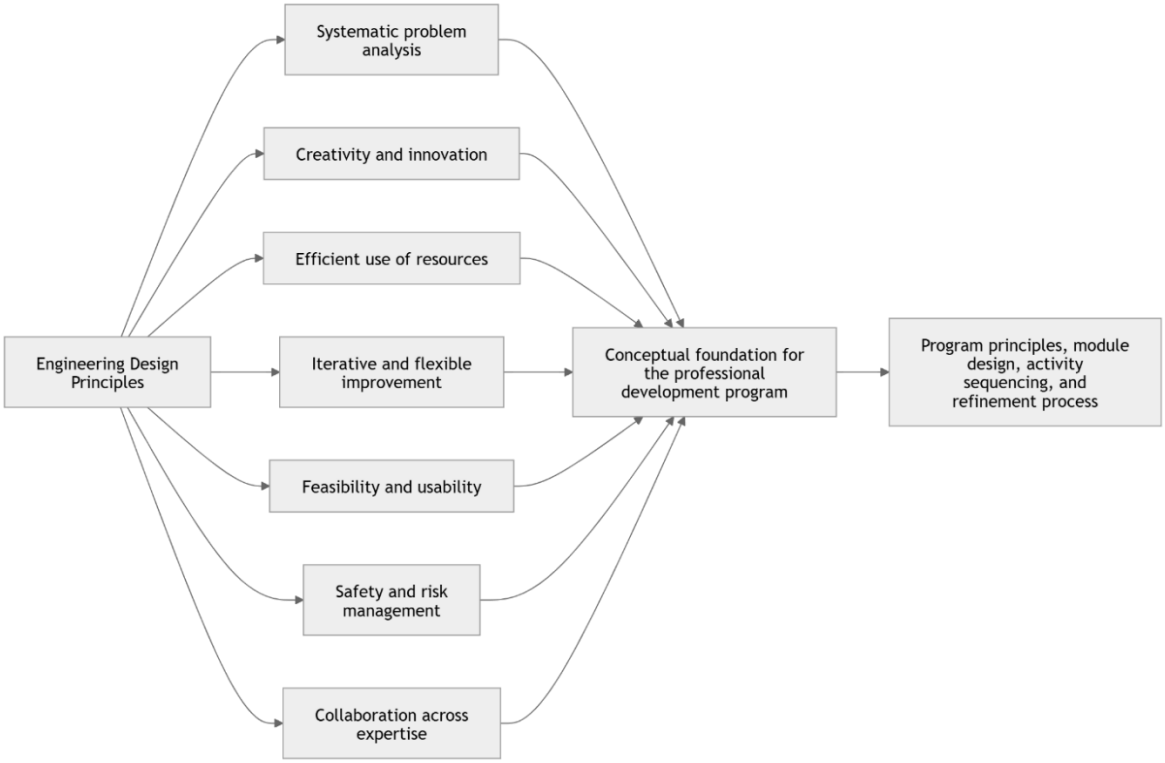


Figure 1. Synthesized engineering design principles as the conceptual foundation for program development

3.1.3 Content Validity of the Competency Framework and Related Instruments

Five experts reviewed the definitions, sub-competencies, behavioral indicators, and related instruments. Content validity was examined using IOC, while qualitative comments were used to improve wording, conceptual clarity, and practical applicability.

For the competency framework, IOC values across the 15 indicators ranged from 0.80 to 1.00, indicating that all items met the acceptable criterion. Most items received IOC = 1.00, while three items—Item 1.3, Item 3.1, and Item 4.2—received IOC = 0.80, suggesting the need for minor refinement in wording and scope (Table 2).

Table 2. IOC Values of the Synthesized Competency Framework for Science Teachers' Learning Innovation Competency

Sub-competency	**Behavioral Indicator**	**IOC**
Preparing	1.1 Understanding target learners and identifying their needs	1.00
	1.2 Defining problems and objectives for innovation development	1.00
	1.3 Reviewing supporting concepts, theories, and principles	0.80
	1.4 Understanding fundamental principles of learning innovation	1.00
Creating	2.1 Generating creative and novel ideas	1.00
	2.2 Designing and developing innovation prototypes	1.00
	2.3 Planning innovation development	1.00
	2.4 Coordinating and collaborating with others	1.00
Implementing	3.1 Determining implementation approaches	0.80
	3.2 Planning implementation management	1.00
	3.3 Examining feasibility and preliminary effectiveness	1.00
	3.4 Summarizing pilot implementation results	1.00
Assessing	4.1 Designing assessment and monitoring methods	1.00
	4.2 Reporting and disseminating innovation	0.80
	4.3 Improving innovation based on evidence and feedback	1.00

Note. IOC values of 0.80 or above were considered acceptable.

Expert comments indicated that the overall framework was conceptually appropriate, but some indicators needed clearer wording and stronger behavioral specificity. In response, wording was revised to clarify the meaning of reviewing supporting theories, linking implementation planning to actual lesson plans or classroom activities, and broadening the meaning of dissemination beyond online channels, while retaining the original four-domain, 15-indicator structure.

The seven engineering design principles were also rated by the same experts using a 5-point appropriateness scale. All principles were rated at a high level, with mean scores ranging from 4.20 to 4.40. The highest-rated principles were systematic problem analysis, creativity and innovation, iterative improvement, feasibility and usability, and collaboration; efficient resource use and safety/risk management received slightly lower but still high ratings (Table 3).

Table 3. Expert Ratings of the Synthesized Engineering Design Principles

Engineering Design Principle	Mean	Level
Systematic problem analysis	4.40	High
Creativity and innovation	4.40	High
Efficient use of resources	4.20	High
Iterative and flexible improvement	4.40	High
Feasibility and usability	4.40	High
Safety and risk management	4.20	High
Collaboration across expertise	4.40	High

These results suggest that the synthesized engineering design principles were appropriate as the conceptual foundation for the program. Experts also recommend making the relationship between each engineering design principle and the targeted teacher's competencies more explicit in the program structure and activity design.

3.2 Phase 2: Program Development and Refinement

3.2.1 Structure and Components of the Developed Program

Using the synthesized competency framework and engineering design principles, the researcher developed a professional development program to enhance science teachers' learning innovation competency through an engineering design approach. The program was structured to ensure coherence among the conceptual foundation, program principles, process steps, target competencies, and core learning activities.

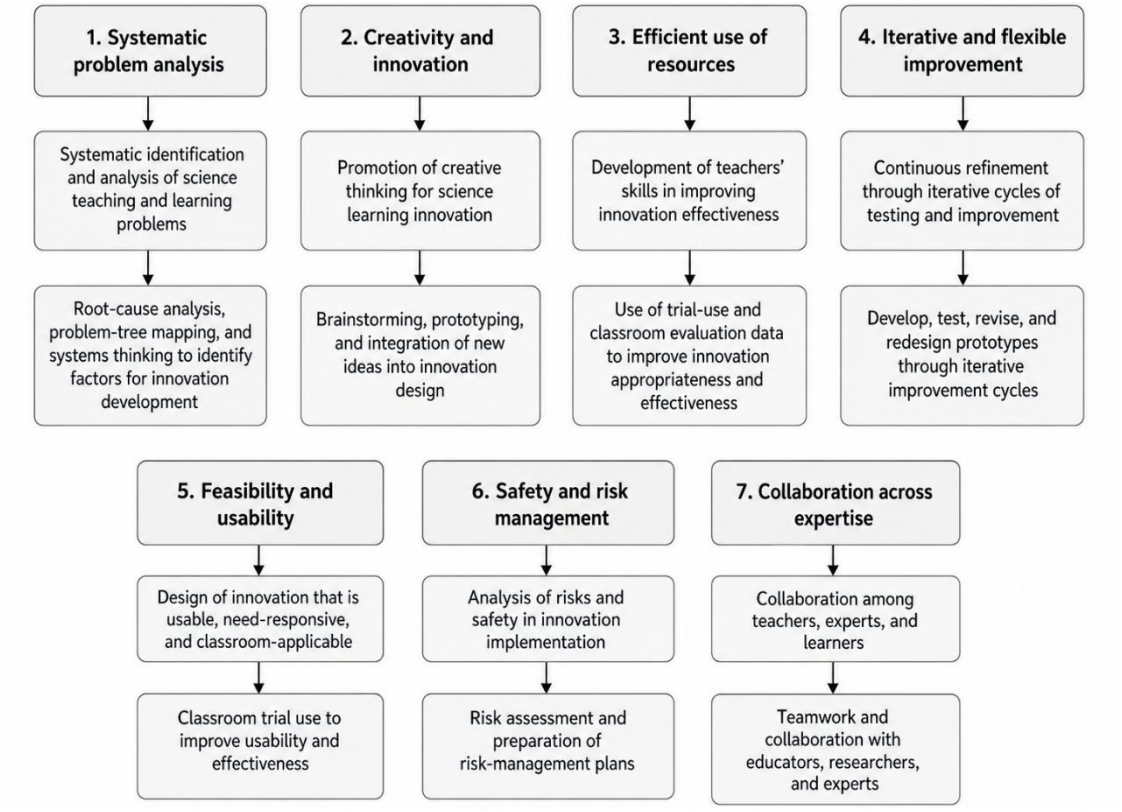


Figure 2. Translation of Engineering Design Principles into Program Principles and Activity Guidelines

The seven engineering design principles were translated into program principles and practical activity guidelines suitable for science teacher development. This translation aligned program principles, target competencies, learning activities, expected evidence, and assessment directions within the same conceptual logic (Figure 2).

Operationally, the program was organized into eight steps adapted from the engineering design approach: Identify the Problem, Research and Gather Information, Brainstorm and Develop Solutions, Design and Plan, Create a Prototype, Test and Evaluate, Improve and Redesign, and Implement and Monitor. To make the process manageable, these steps were reorganized into six training modules. Modules 1-5 corresponded mainly to Steps 1-5, while Module 6 integrated Steps 6-8 to allow sufficient time for classroom testing, reflection, and refinement (Table 4).

Table 4. Integration of Program Principles, Engineering Design Steps, and Training Activities

Related Program Principle(s)	Engineering Design Step	Core Training Activity	Related Module
Systematic identification and analysis of science teaching and learning problems	Step 1: Identify the Problem	Teachers identify authentic classroom problems, analyze their causes, and define innovation goals based on learner needs and classroom context.	Module 1
Systematic identification and analysis of science teaching and learning problems; Analysis of risk and safety in the use of science learning innovation	Step 2: Research and Gather Information	Teachers collect relevant information, examine supporting concepts and evidence, and consider safety and risk issues related to innovation development.	Module 2
Promotion of creative thinking for science learning innovation	Step 3: Brainstorm and Develop Solutions	Teachers generate creative ideas and alternative innovation solutions through brainstorming, thinking tools, and reflective idea development.	Module 3
Design of innovation that is usable, responsive to learners' needs, and applicable in real classrooms; Collaboration among teachers, experts, and learners	Step 4: Design and Plan	Teachers design and plan innovations in ways that are practical, learner-responsive, and collaborative, while preparing resources and development plans.	Module 4
Continuous refinement through iterative cycles of testing and improvement	Step 5: Create a Prototype	Teachers create an initial prototype that can be tried out, examined, and further improved.	Module 5
Development of teachers' skills in improving the effectiveness of learning innovation	Step 6: Test and Evaluate	Teachers test the innovation, collect evidence, and evaluate feasibility and preliminary effectiveness to guide improvement.	Module 6
Continuous refinement through iterative cycles of testing and improvement; Collaboration among teachers, experts, and learners	Step 7: Improve and Redesign	Teachers revise or redesign the innovation based on testing results, feedback, and collaborative reflection.	Module 6
Collaboration among teachers, experts, and learners; Analysis of risk and safety in the use of science learning innovation	Step 8: Implement and Monitor	Teachers implement the refined innovation in classroom contexts and monitor its use in collaboration with relevant stakeholders.	Module 6

The program was designed as a seven-week, 72-hour professional development experience emphasizing active participation, school-based tasks, and field implementation in authentic settings. This structure was intended to support teachers in developing innovations from real classroom problems rather than treating innovation development as a purely theoretical exercise.

Each module was given a title reflecting its developmental focus and aligned with one or more target sub-competencies. The six modules were: 1) Discovering Problems for Innovation, 2) Exploring and Gathering Insights for Development, 3) Igniting Creative Ideas for Solutions, 4) Planning and Designing Functional Innovations, 5) Prototyping and Testing Feasibility, and 6) Improving, Refining, and Implementing in Classrooms.

Together, these modules provided a structured pathway from problem identification to innovation design, pilot use, evaluation, refinement, and implementation (Table 5).

Table 5. Structure of the Professional Development Program

Module (Hours)	Module Title	Engineering Design Step(s)	Module Objective(s)	Targeted Sub-competencies	Key Activities
Module 1 (12)	Discovering Problems for Innovation	Step 1: Identify the Problem	To analyze learners and classroom contexts, identify problems, and define clear innovation goals	1.1, 1.2	Classroom problem analysis; target-group analysis; analytical questioning; innovation problem framing
Module 2 (12)	Exploring and Gathering Insights for Development	Step 2: Research and Gather Information	To review documents, concepts, and trustworthy information sources and synthesize them into usable insights for innovation development	1.3	Literature search and synthesis; concept analysis; linking ideas to innovation directions
Module 3 (12)	Igniting Creative Ideas for Solutions	Step 3: Brainstorm and Develop Solutions	To understand innovation principles and generate new and context-responsive innovation ideas	1.4, 2.1	Creative thinking techniques; brainstorming/TRIZ; thinking tools; reflective ideation
Module 4 (12)	Planning and Designing Functional Innovations	Step 4: Design and Plan	To design and develop prototypes, plan innovation development, and engage in professional collaboration	2.2, 2.3, 2.4	Design canvas/action plan; resource and timeline planning; digital/AI-assisted design; teamwork
Module 5 (12)	Prototyping and Testing Feasibility	Step 5: Create a Prototype	To determine practical implementation approaches, manage innovation use, and examine preliminary feasibility and effectiveness	3.1, 3.2, 3.3	Prototype development; trial use/simulated use; collection of reflective data; feasibility and effectiveness review
Module 6 (12)	Improving, Refining, and Implementing in Classrooms	Steps 6-8: Test and Evaluate; Improve and Redesign; Implement and Monitor	To summarize pilot use, design monitoring and assessment procedures, and prepare for dissemination and further refinement	3.4, 4.1, 4.2, 4.3	Analysis of pilot results; design of monitoring tools; preparation of dissemination materials; planning for the next cycle of innovation improvement

3.2.2 Expert Evaluation of Program Quality

Five experts evaluated the developed program in two areas: overall program quality and module-level training activities. Overall, the program was rated at a high to very high level of appropriateness, with most mean scores ranging from 4.2 to 5.0, indicating that its structure, learning methods, participant engagement, and expected outcomes were considered feasible and appropriate for implementation.

Experts nevertheless identified several areas for improvement, including strengthening the rationale for adopting the engineering design approach, standardizing module descriptions, making alignment among competencies, activities, and assessment more explicit, and increasing flexibility to reduce teachers' workload and better support learning in authentic school contexts.

At the overall-program level, the highest ratings were found for program goals, target participants, participant qualifications, learning methods and participation, expected outcomes, expected benefits, and overall program structure, all of which received mean scores of 5.00. The lowest-rated components were the program rationale ($M = 4.20$, $SD = 0.84$) and training duration ($M = 4.40$, $SD = 0.55$), suggesting a need for stronger theoretical grounding and greater flexibility in time allocation (Table 6).

Table 6. Overall Expert Evaluation of Program Quality (n = 5)

Evaluation Item		Mean	SD
1	Program rationale	4.20	0.84
2	Learning concept embedded in the program	4.40	0.89
3	Program objectives	4.80	0.45
4	Target competencies of participants	4.80	0.45
5	Program goals	5.00	0.00
6	Target participants	5.00	0.00
7	Participant qualifications	5.00	0.00
8	Training duration	4.40	0.55
9	Learning methods and participation	5.00	0.00
10	Expected outcomes	5.00	0.00
11	Expected benefits	5.00	0.00
12	Evaluation methods and success indicators	4.80	0.45
13	Overall program structure	5.00	0.00

At the module level, mean ratings ranged from 4.71 to 4.89. The highest-rated modules were Module 5 and Module 6 (M = 4.89), followed by Module 4 (M = 4.84), while Modules 1-3 received slightly lower but still high ratings (M = 4.71-4.76). These findings suggest that the later modules were viewed as especially coherent and practically applicable, whereas the earlier modules needed more clarification in conceptual focus, activity sequencing, and supporting materials (Table 7).

Table 7. Summary Statistics of Expert Evaluation Across Modules (n = 5)

Module	Mean	SD	Mean Range
Module 1: Discovering Problems for Innovation	4.71	0.19	4.4-5.0
Module 2: Exploring and Gathering Insights for Development	4.76	0.20	4.4-5.0
Module 3: Igniting Creative Ideas for Solutions	4.76	0.17	4.6-5.0
Module 4: Planning and Designing Functional Innovations	4.84	0.22	4.4-5.0
Module 5: Prototyping and Testing Feasibility	4.89	0.16	4.6-5.0
Module 6: Improving, Refining, and Implementing in Classrooms	4.89	0.10	4.8-5.0

Note. Mean values were calculated from the average scores of all evaluation items within each module.

Qualitative comments showed that the modules were conceptually promising and practically feasible when role descriptions, structure, and expected outputs were clear. Recurring concerns included insufficient clarity of key concepts, limited alignment between activity detail and allocated time, discontinuity across modules, and the need for more explicit evidence-based assessment criteria (Table 8).

Table 8. Qualitative Summary of Strongest Aspects and Areas for Improvement Across Modules

Module	Strongest Aspects	Areas for Improvement
Module 1 Discovering Problems for Innovation	Clear potential for active learning; strong reviewer agreement on facilitator/participant roles; relevant focus on classroom problems	Clarify the module's key concept; specify problem types and analysis methods; improve alignment between activity detail and time allocation; provide clearer instructions and examples
Module 2 Exploring and Gathering Insights for Development	Strong competency focus; potential for systematic inquiry and information use	Clarify data types and sources; improve activity instructions; provide examples for faster work within limited time; strengthen technology-supported searching and synthesis
Module 3 Igniting Creative Ideas for Solutions	Strong potential to stimulate idea generation; generally appropriate module purpose	Make links among problems, theories, and innovation ideas more explicit; connect reflective tasks more clearly to outputs from Module 2; improve guidance in supporting documents
Module 4 Planning and Designing Functional Innovations	Strong role structure and documentation; good emphasis on planning and collaboration	Clarify the meaning of functional design; make design principles more explicit; introduce assessment tool design earlier; reduce time pressure through advance preparation
Module 5 Prototyping and Testing Feasibility	Most clearly written module; strong coherence between purpose, process, and prototype development; suggested as a model for other modules	Allocate more time for actual prototype development; strengthen objective and evidence-based assessment criteria; provide more examples of data collection tools
Module 6 Improving, Refining, and Implementing in Classrooms	Highest consistency of expert ratings; strong emphasis on refinement and classroom use	Clarify sequencing of assessment preparation; provide more concrete evaluation examples; focus criteria on contextual appropriateness rather than broad generalizability

At the module level, Module 1 was seen as relevant and promising, but experts recommended clarifying the concept of problem identification, specifying problem types and analysis methods, and improving activity instructions. Module 2 was considered appropriate, though experts suggested clearer information sources, more explicit procedures, and stronger use of technology for searching and synthesis. Module 3 was positively evaluated, but experts recommended clearer links among problems, theories, and innovation ideas, as well as stronger continuity with outputs from the previous module.

For Module 4, experts suggested clarifying key terms such as functional and making design principles more explicit as planning and evaluation criteria. Module 5 was considered one of the strongest modules and was even suggested as a model for revising other modules, although more time and more objective criteria were still recommended. Module 6 was also highly rated, but experts suggested clearer sequencing of assessment preparation and stronger emphasis on contextual appropriateness rather than broad applicability across all settings. Overall, the experts agreed that the program was highly appropriate and feasible, while recommending improvements in conceptual clarity, alignment, and evidence used in authentic school contexts.

3.2.3 Pilot Refinement Findings from Participants and Observers

The revised program was piloted over three days with 14 science and technology teachers from one school. Three observers participated throughout the pilot. The pilot focused on three core modules—Module 1, Module 3, and Module 4—because they represented the upstream stages of innovation development and were most suitable for examining the clarity of the activity sequence, operational feasibility, and usability of the support tools.

In Module 1, activities effectively engaged all participants by starting from their own classroom experiences. Observers noted that this approach anchored the innovation process in authentic practice. However, participants needed stronger scaffolding for reflection and problem framing. Although many teachers could describe classroom difficulties, they were not always able to synthesize them into innovation-oriented problem statements. The use of the 5 Why technique was also not consistently connected to the broader purpose of innovation development. Observers suggested making participant-generated information more visible to the whole group through shared displays or collaborative platforms to support collective analysis and decision making.

In Module 3, tools such as reflection cards and idea prompts were useful in stimulating thinking. However, the process was not always sufficiently connected to participants' prior data and classroom evidence, making it difficult to judge whether the generated ideas were genuinely innovative and context-responsive. Observers also suggested making task difficulty more comparable across groups, shifting some tasks from individual to paired or small-group work, and strengthening the presentation stage with structured peer and facilitator feedback. These findings suggest that Module 3 had strong potential for stimulating creative thinking but required stronger

links to prior data, more structured interaction, and more explicit feedback processes.

In Module 4, a notable strength was the opportunity for teachers to experiment with prompt design for ChatGPT, which participants found timely and motivating. However, prompt use needed to be more clearly anchored in the selected classroom problem and intended innovation context. Without such grounding, the activity risked becoming a stand-alone technology exercise rather than part of the innovation design process. Observers also recommended linking prompt use more explicitly to the chosen problem, the intended form of innovation, and the evidence to be collected for later evaluation.

Across the three piloted modules, several recurring themes emerged. The program needed: (1) more explicit structures for reflection and documentation, (2) greater visibility of participant-generated information for collective interpretation, (3) stronger continuity among prior data, generated ideas, and evaluation criteria, (4) more structured reflective feedback processes, and (5) clearer links between digital tools, selected problems, and later evaluation.

Overall, the pilot findings indicate that the program showed clear promise in supporting teachers' innovation-oriented thinking in an authentic professional development context. However, the activities and support tools still required refinement to strengthen procedural clarity, conceptual continuity, and alignment with competency-based assessment before full-scale implementation.

3.2.4 Participant Self-Assessment and Satisfaction After the Pilot

After the three-day pilot, feedback was collected from 14 participants through a self-assessment of learning innovation competency and a satisfaction questionnaire.

For self-assessed learning innovation competency, the overall mean score was 3.62, indicating a moderate to relatively high level. The scale showed high internal consistency (Cronbach's alpha = .897). By domain, the highest mean was found for Preparing (M = 3.71), followed by Implementing (M = 3.64), Assessing (M = 3.60), and Creating (M = 3.52). This pattern suggests that participants felt more confident in identifying learner needs, understanding innovation principles, and planning for implementation than in the more demanding tasks associated with designing, refining, and evaluating innovation in practice. At the item level, the highest-rated indicators were understanding the principles of learning innovation (M = 3.86) and determining implementation approaches (M = 3.93), whereas lower scores were found for planning innovation development (M = 3.29), examining feasibility and preliminary effectiveness (M = 3.43), and reporting and disseminating innovation (M = 3.43) (Table 9).

Table 9. Participant Self-Assessment of Learning Innovation Competency After the Pilot (n = 14)

Competency Domain	Mean	SD
Preparing	3.71	0.38
Creating	3.52	0.46
Implementing	3.64	0.34
Assessing	3.60	0.47
Overall	3.62	0.34

Note. Cronbach's alpha for the 15-item self-assessment scale = .897

For participant satisfaction, the overall mean score was 4.47, and internal consistency was also high (Cronbach's alpha = .878). The highest-rated item was alignment with the school context (M = 4.79), followed by promotion of active learning (M = 4.64) and connection to teacher competency development (M = 4.57). Lower—though still high—ratings were found for applicability of knowledge to practice (M = 4.29), contribution to strengthening teacher competency (M = 4.29), engaging and stimulating activities (M = 4.36), and motivation for future application (M = 4.36). These results suggest that participants viewed the program positively overall, particularly in terms of contextual relevance and practice-oriented learning, while also indicating room for improvement in transfer to practice and longer-term innovation support (Table 10).

Table 10. Participant Satisfaction with the Pilot Program (n = 14)

Indicator	Mean	SD
Program aligned with school context	4.79	0.43
Program promoted active learning	4.64	0.50
Program linked to teacher competency development	4.57	0.51
Program responded to participants' needs	4.50	0.52
Activities supported knowledge exchange	4.50	0.52
Training duration was appropriate	4.50	0.52
Activities were engaging and participatory	4.36	0.50
Program inspired motivation for future application	4.36	0.50
Knowledge could be applied in practice	4.29	0.47
Program strengthened teachers' competency	4.29	0.47
Overall	4.47	0.32

Note. Cronbach's alpha for the 15-item satisfaction scale = .878

The self-assessment and satisfaction findings indicate that the pilot program was positively received and perceived as relevant and context-responsive. At the same time, the relatively lower scores in later-stage competencies—especially planning, feasibility evaluation, and dissemination—suggest the need for further refinement to strengthen the bridge between idea generation, evidence-based implementation, and sustained innovation use in authentic school contexts.

3.2.5 Revisions Made After the Pilot

Following expert review and pilot refinement, the researcher revised the program to improve its clarity, coherence, and practical usability in authentic school contexts. The revisions addressed the conceptual foundation, program structure, competency progression, learning activities, technology use, and assessment tools.

First, the conceptual foundation was strengthened by linking the program more explicitly to the engineering design approach and to widely recognized principles of teacher professional development, including content-focused learning, active participation, coherence with school contexts, and collective participation with reflection (Garet et al., 2001; Desimone, 2009; Darling-Hammond et al., 2017; Loucks-Horsley et al., 2010). Module descriptions were also standardized to include key concepts, objectives or target competencies, content, activities, roles, media and tools, expected outcomes, expected evidence, and evidence-based assessment criteria.

Second, the original competency progression was reorganized into three broader developmental phases: (1) identifying and analyzing problems, (2) designing and developing innovation, and (3) piloting, refining, and evaluating innovation based on evidence. This revision made the developmental sequence more coherent and more clearly aligned with the logic of engineering design.

Third, module activities—especially in Modules 1-3—were revised to strengthen the sequence of thinking, analysis, synthesis, and reflection. Reflection prompts were made more explicit, the use of the 5 Why technique was systematized, and shared spaces such as online collaborative boards or flip charts were introduced to make participant-generated information more visible and usable for collective interpretation and decision making. Some tasks were also shifted from individual to paired or small-group work to support collaborative learning and stronger continuity across modules.

Fourth, the use of digital tools and support media was strengthened. Online collaborative platforms were incorporated to support idea sharing and feedback, and AI-based tools were integrated to assist in information searching, problem analysis, and idea generation. Their use was revised to be explicitly connected to the selected problem, the evidence to be collected, and the criteria for evaluation so that technology functioned as part of the innovation design process rather than as a separate technical exercise (Koehler & Mishra, 2009).

Fifth, the rubrics and related assessment tools were revised to include more concrete and objective criteria, such as functional completeness, feasibility of classroom use, and contextual appropriateness. Assessment design was also moved earlier in the process—particularly to Module 4—so that evaluation became part of the design stage rather than occurring only after pilot implementation. In addition, minimum evidence requirements were specified for each module to support more reasoned decisions about innovation refinement (Guskey, 2002; Desimone, 2009).

Overall, the post-pilot revisions show that the final version of the program was systematically refined in response to converging evidence from expert review and pilot implementation. As a result, the program gained a clearer conceptual foundation, more coherent developmental sequencing, more structured activity flow, stronger integration of digital tools, and more explicit evidence-based assessment procedures, thereby increasing its readiness for full-scale implementation in authentic school contexts (Table 11).

Table 11. Summary of Revisions Made After Expert Review and Pilot Refinement

Revision Area	Issues Identified	Revisions Made
Conceptual foundation and rationale	Program rationale and academic grounding were not sufficiently explicit; core concepts were not communicated consistently across modules	Strengthened the theoretical foundation by linking the program more explicitly to engineering design and teacher professional development principles; standardized conceptual explanations across modules
Program structure and module format	Module descriptions lacked consistency in structure and presentation	Standardized all modules to include key concepts, objectives/competencies, content, activities, roles, media/tools, expected outcomes, evidence/artifacts, and assessment criteria
Competency progression	Original competency targets were too extensive for the available training time; developmental sequence was unclear	Reorganized competency progression into three broader developmental phases: problem identification and analysis, innovation design and development, and evidence-based piloting and refinement
Learning activities and reflective processes	Reflection lacked structure; important information was not sufficiently visible to the group; continuity across modules was limited	Added structured reflection prompts, more systematic use of 5 Why, shared collaborative spaces, and stronger continuity between outputs from earlier and later modules
Technology and support tools	Use of digital tools and AI was not always clearly integrated with innovation design	Added online collaborative platforms and AI-supported tools, while linking their use explicitly to selected problems, evidence collection, and evaluation criteria
Assessment criteria and instruments	Assessment criteria were too impressionistic; evaluation tools were introduced too late in the process	Added more objective, evidence-based criteria; moved assessment tool design to earlier stages, especially Module 4; specified minimum evidence requirements for each module

4. Discussion

The findings of this study show that the engineering design approach can be translated into a systematic developmental logic for a professional development program aimed at enhancing science teachers' learning innovation competency. Rather than treating innovation development as a set of isolated workshop activities, the study demonstrates that this competency can be organized into a coherent framework and operationalized through modules and activities grounded in authentic classroom problems. Importantly, this article does not claim program effectiveness in terms of outcome variables; instead, it shows that the program was conceptually synthesized, expert-validated, and empirically refined through pilot implementation in a real school context.

A key contribution of the study is the synthesis of science teachers' learning innovation competency into four sub-competencies—Preparing, Creating, Implementing, and Assessing—together with 15 behavioral indicators. By translating a broad construct into a structured competency framework with observable indicators, the study makes learning innovation more conceptually explicit and more traceable for development and assessment (Peñalver et al., 2018; Cukurova & Miao, 2024). More importantly, it functioned not only as a descriptive model but also as a design logic for structuring program activities and aligning competencies, learning experiences, and assessment. This is especially important because expert feedback repeatedly emphasized the need for stronger alignment among competencies, activities, and assessment. The findings therefore reinforce the importance of coherence in professional development design, as also highlighted in prior studies on effective teacher learning (Desimone, 2009; Garet et al., 2001).

The findings from Phase 2 further indicate that the engineering design approach could be transformed into an eight-step process and organized into six modules that teachers could realistically follow. This suggests that engineering design functions not merely as a theoretical metaphor but as an operational structure for professional learning. Expert evaluation showed high to very high levels of appropriateness across most aspects of the program, supporting the feasibility of the overall design. At the same time, expert comments revealed that program quality depends not only on conceptual soundness but also on how clearly the program is communicated. In this study, inconsistent module presentation, insufficiently explicit rationale, and unclear mapping among competencies, activities, and evidence were identified as weaknesses despite generally positive ratings. This suggests that clarity of communication and structural consistency should be treated as core dimensions of program quality rather than as merely presentational matters (Darling-Hammond et al., 2017; Loucks-Horsley et al., 2010).

The pilot refinement findings add practical depth to these results by showing where teachers encountered bottlenecks in innovation-oriented work. In Module 1, teachers could share authentic classroom problems, but they needed stronger scaffolding to transform experience into analyzable problem statements. In Module 3, the main challenge was not idea generation itself, but linking new ideas to prior data, prior teaching practice, and relevant theoretical support. In Module 4, AI-supported design tools were promising, but they needed to be explicitly connected to the selected problem, the intended innovation, and later evaluation criteria. Taken together, these findings suggest that successful innovation-oriented teacher learning depends not only on what teachers are asked to do, but also on the cognitive and procedural scaffolds that support movement from reflection to analysis, from analysis to ideation, and from ideation to evidence-based design (Desimone, 2009; Loucks-Horsley et al., 2010).

Another important implication concerns the role of visibility, shared interpretation, and structured feedback in professional development. The pilot showed that teachers benefited when their ideas, problems, and design decisions were made visible to the group and when feedback was supported through prompts, checklists, or common reference points. This suggests that innovation-oriented professional development should be understood not only as individual skill building, but also as participation in a shared design space where evidence, ideas, and revisions can be collectively examined (Garet et al., 2001; Vescio et al., 2008). In this respect, post-pilot revision such as adding reflection prompts, making participant-generated data visible in shared spaces, shifting some tasks from individual to pair or small-group work, and integrating collaborative digital tools—can be interpreted as responses to the social and cognitive conditions needed for deeper professional learning.

The post-pilot revisions also clarify the mechanism by which the program was intended to work. The revised version placed greater emphasis on a clear conceptual foundation, standardized module structure, stronger continuity across modules, and earlier integration of evidence-based assessment. This suggests that the program was intended to support teacher innovation not simply by exposing teachers to new ideas, but by guiding them through a structured learning architecture in which problem analysis, idea development, design, testing, and refinement were explicitly linked. In this sense, the program appears to work through the combination of content-focused professional learning, active participation, contextual coherence, iterative design, and evidence-based reflection. This interpretation is consistent with the broader literature on effective professional development and helps explain why revision was needed not only in content but also in sequencing, support tools, and assessment design (Darling-Hammond et al., 2017; Desimone, 2009; Garet et al., 2001).

This study also offers practical implications for science teacher professional development by providing a validated competency framework for designing innovation-related learning activities and assessment, a structured program model that translates engineering design into teacher development steps and modules, and practical design features that may improve usability in real school contexts, such as clearer reflection protocols, more visible shared data, stronger feedback systems, more flexible task structures, and closer integration of digital tools with contextual problems and evidence collection (Desimone, 2009; Garet et al., 2001; Loucks-Horsley et al., 2010; Darling-Hammond et al., 2017; Koehler & Mishra, 2009; Vescio et al., 2008). In addition, the integration of digital tools and AI-related support should be understood not merely as technical enhancement, but as part of teachers' pedagogical design capacity, which is consistent with the logic of technological pedagogical content knowledge (Koehler & Mishra, 2009).

Several limitations should also be acknowledged. First, the pilot refinement involved a relatively small group of teachers from a single school and included only three modules rather than the full program. The findings should therefore be interpreted primarily as evidence of program appropriateness, feasibility, and refinement needs rather than of program effectiveness. Second, the self-assessment and satisfaction data were useful in showing positive perceptions and self-reported competency-related practice, but they remain limited as indicators of actual long-term change in teacher performance. Third, the pilot was conducted in a bounded and supportive training context, so implementation challenges in broader or more varied settings may differ. Finally, because the study focused on development and refinement, it did not yet examine the effects of the program on teachers' actual innovation products, sustained classroom implementation, or student outcomes. These limitations should be considered when interpreting the findings and judging their generalizability (Anderson-Cook, 2005).

Despite these limitations, the findings remain important because they show how a professional development program for science teachers can be built through a staged and evidence-informed process rather than through intuitive workshop design alone. The study contributes both a conceptual product—a competency framework—and a developmental product—a refined professional development program—each shaped through expert review and pilot evidence. Thus, the main contribution of this article lies not in demonstrating program impact, but in presenting a program model that has been systematically developed, validated, and refined to the

point of practical readiness for further implementation and study. Future research should examine full implementation of the program, including pre-post changes in teacher competency, the quality of the innovations produced, the sustainability of classroom use, and possible outcomes for student learning.

5. Conclusion

This study aimed to develop a professional development program to enhance science teachers' learning innovation competency through an engineering design approach within a research and development framework. The findings can be summarized in two phases. In Phase 1, a competency framework for science teachers' learning innovation competency was synthesized from related literature and organized into four sub-competencies: Preparing, Creating, Implementing, and Assessing. These were further specified through behavioral indicators and validated by experts, with IOC results indicating acceptable content validity.

In Phase 2, the framework was translated into a professional development program structured around eight developmental steps and six training modules. Expert review indicated high to very high appropriateness overall, while also identifying areas for refinement, particularly in conceptual clarity, consistency of module presentation, alignment among competencies, activities, and assessment, and implementation flexibility.

The program was then piloted in an authentic school context with science and technology teachers. Evidence from observation, participant reflection, self-assessment, satisfaction ratings, and expert feedback was used to revise the structure of activities, module sequencing, support tools, and assessment criteria. As a result, the final version of the program became clearer, more coherent, and more responsive to school context, and was judged to be sufficiently developed for subsequent implementation and further investigation of its effects on teacher competency and classroom practice.

Overall, the study contributes both a validated competency framework and a systematically refined professional development program for science teachers. Its main contribution lies not in demonstrating program effectiveness, but in showing how a program for enhancing teachers' learning innovation competency can be developed through a structured process of synthesis, expert review, pilot refinement, and evidence-based revision.

6. Suggestions

1) Suggestions for Practice

The developed program should be implemented over a longer period and with more diverse groups of teachers to examine its flexibility and applicability across different educational settings, school affiliations, grade levels, and resource conditions. This would help determine whether the program can be adapted successfully beyond the context in which it was developed. In addition, schools or teacher education units adopting the program should consider establishing coaching systems or professional learning communities to support continued innovation use and sustain cycles of feedback, reflection, and iterative improvement after the formal training period (Darling-Hammond et al., 2017; Timperley et al., 2007).

Future implementation should continue to emphasize evidence collection, reflective dialogue, and collaborative interpretation of classroom problems and innovation outcomes so that innovation development remains closely connected to authentic teaching and learning needs (Timperley et al., 2007; Vescio et al., 2008).

2) Suggestions for Future Research

Future research should examine the effects of the program on teacher competency through pre-post designs or other outcome-oriented approaches. Such studies would help determine whether the program leads to measurable changes beyond perceived appropriateness and self-reported development. Future studies should also investigate whether teacher-developed innovations influence student learning, classroom engagement, and the quality of science instruction. Longitudinal or case-based studies would be especially valuable for examining how teachers' innovation competency develops over time and how professional change is sustained in practice (Guskey, 2002; Desimone, 2009; Darling-Hammond et al., 2017; Penner-Williams et al., 2019; Visscher et al., 2025).

Further research may also compare implementation across different school contexts or teacher groups to examine how contextual variables—such as workload, school leadership, access to digital tools, or collaborative culture—influence program feasibility and outcomes (Darling-Hammond et al., 2017; Timperley et al., 2007; Nguyen et al., 2021; Landa et al., 2023). Such work would strengthen understanding of the conditions under which innovation-oriented professional development is most effective.

7. Limitations

This study has several limitations. First, the pilot's refinement involved a relatively small group of teachers from only one school, limiting the range of contexts represented. Second, the pilot covered only selected modules

rather than the full program. Third, the study did not examine effectiveness through pre-post measurement, comparison groups, or direct evidence of change in teacher performance or student outcomes. Accordingly, the findings should be interpreted primarily as evidence of the program's appropriateness, feasibility, and readiness rather than its effectiveness.

In addition, the self-assessment and satisfaction data provided useful information about participants' perceptions and self-reported competency-related practice, but they cannot be taken as strong evidence of long-term change or actual classroom impact. Therefore, this article should be understood as reporting the development and refinement of the program, while more rigorous outcome evaluation remains a task for the next phase of research.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Obtained.

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Data sharing statement

No additional data are available.

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