Scaffolding and Questioning in Engineering Design-Oriented STEM: A Qualitative Analysis of High School Technology Teachers' Pedagogical Strategies and Perspectives

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Abstract

Engineering design-oriented STEM courses have been recognized as important approaches for cultivating students' problem-solving and integrative thinking skills. Such instruction requires students to engage in challenging phases of the engineering design process, while teachers coordinate pedagogical actions such as curriculum unit design, scaffolding, and purposeful questioning to support iterative problem-solving. However, teachers' pedagogical perspectives and instructional decision-making in these contexts remain insufficiently examined. This qualitative study investigates high school Technology teachers' educational beliefs, curriculum design models, and the scaffolding and questioning strategies they employ to guide student engagement in engineering design-oriented STEM courses. Fourteen teachers from diverse regions in Taiwan participated in semi-structured online interviews (approximately 60–90 minutes each). The interview protocol, grounded in prior literature, addressed three dimensions: (1) educational beliefs, (2) curriculum design models, and (3) learning scaffolds and questioning strategies. Interview data were transcribed verbatim and analyzed through iterative coding and thematic analysis aligned with these dimensions. Triangulation was conducted through comparison with relevant literature and course documents provided by some participants. The findings reveal a strong consensus among teachers on the importance of systematically guiding students through the engineering design process to develop their ability to apply interdisciplinary knowledge for solving complex problems. Teachers commonly adopt phased curriculum structures, supported by learning portfolios and instructional exemplars, progressing from foundational skill development to student-centered engineering design projects. Instructional emphasis is placed on problem scoping and noticing, as well as predictive analysis, modeling, and evidence-based testing using interdisciplinary knowledge. Throughout the design process, teachers strategically employ diverse and interactive questioning to support students' reasoning and decision making without providing direct solutions, thereby promoting reflective learning and student autonomy. This study offers implications for curriculum design and instructional strategies in engineering design-oriented STEM education.

Key Words: Engineering Design-Oriented STEM, High School, Scaffolding and Questioning Strategies, Technology Teacher

1 INTRODUCTION

In recent trends in K-12 STEM (Science, Technology, Engineering, and Mathematics) education, engineering design-oriented STEM courses have been widely recognized as important instructional approaches for cultivating students' problem-solving skills, integrative knowledge, and the ability to apply their learning in real-world contexts (Kidd et al., 2025). Under the concept of interdisciplinary integration, engineering design is positioned as a pivotal cognitive and learning process that connects knowledge from science, mathematics, and technology (Kelley & Knowles, 2016; National Research Council [NRC], 2012; Roehrig et al, 2021). In Taiwan, high school technology education has also explicitly emphasized the importance of developing students' engineering design thinking (Ministry of Education, 2018).

STEM project-based courses centered on engineering design typically require students to engage in a series of challenging design processes, including steps such as problem identification, information gathering, idea development, predictive analysis, prototyping, testing, and optimization (NRC, 2012; Purzer, 2018; Simarro & Couso, 2021; Wells, 2016). Throughout this process, students must continuously employ divergent and convergent questioning to connect and apply disciplinary knowledge in order to identify the core problems to be addressed and effective solutions (Dym et al., 2005). However, prior research has shown that for secondary-level students, clearly defining core problems and effectively linking and applying interdisciplinary knowledge during engineering design activities remains a highly challenging task (English, 2016; Hughes & Denson, 2021). Students also tend to overemphasize making and final products, while neglecting problem analysis, predictive reasoning, and evidence-based testing and optimization (Crismond & Adams, 2012; Rees Lewis et al., 2023).

Engineering design-oriented STEM courses at the secondary level frequently adopt learning models such as project-based learning, problem-based learning, and inquiry-based learning. Although these models emphasize a learner-centered approach, the guiding role played by the teacher remains a critical factor in determining whether students can effectively engage in learning and apply disciplinary knowledge to solve design problems (Wells, 2016). Previous research has indicated that appropriate learning scaffolds assist students in maintaining their learning direction, focusing on key problems, and progressively internalizing the knowledge and thinking skills required for professional practice (Hmelo-Silver et al., 2007). During the engineering design process, insufficient scaffolding may hinder students' ability to grasp core problems and apply existing knowledge for predictive analysis, and may compromise the depth and quality of problem-solving when challenges arise during prototyping and testing (Hughes & Denson, 2021).

In engineering design-oriented STEM courses, teachers have commonly employed engineering design journals, portfolios, or structured worksheets as scaffolds to support students' documentation of design decisions and reflection on their learning processes (Hertel et al., 2017; Kelley, 2014). However, learning scaffolds should not be viewed merely as pre-designed

instructional tools; rather, they represent a dynamic support process that requires ongoing adjustment based on students' learning states (van de Pol et al., 2010). In open-ended engineering design contexts, where students' difficulties are often diverse and individualized, effective scaffolding depends largely on teachers' ability to notice students' thinking and learning difficulties in real time.

Research on teacher noticing indicates that teachers' professional expertise is demonstrated not only in their selection of instructional strategies but also in their ability to attend to students' learning performances and provide appropriate responses (Jacobs et al., 2010; van Es & Sherin, 2002). This process typically comprises three interconnected dimensions: attending to students' key behaviors, interpreting students' understanding and difficulties, and deciding how to respond (Jacobs et al., 2010). In engineering design-oriented STEM courses, teacher noticing is particularly critical given the contextualized and evolving challenges students encounter across different design stages.

Among teachers' instructional actions, questioning is one of the most frequently used classroom practices. It guides students to re-examine design goals and constraints and supports reflection on design decisions and knowledge application (Wells, 2016). Walsh and Sattes (2011) argue that high-quality questioning promotes higher-order thinking and identify several types of questions that support deeper learning, including "Probing Questions," which scaffold students' learning and understanding, and "Interpretation Questions," which encourage students to generate preliminary inferences based on given information or evidence. These questioning strategies must be flexibly combined and adapted in response to students' learning states and task demands to effectively support engineering design learning.

However, determining when to intervene, how to question, and how to strike a balance between providing guidance and allowing student autonomy remains a highly professional and context-dependent pedagogical judgment. Although international research (Kidd et al., 2025) has increasingly focused on curriculum design, interdisciplinary integration strategies, and students' performance in engineering design-oriented STEM courses, there remains a lack of in-depth empirical research on how teachers, in authentic classroom contexts, notice students' learning states during the engineering design process based on their educational beliefs and curriculum design thinking, and subsequently guide learning through dynamic scaffolding and questioning strategies.

Therefore, this study aims to investigate the pedagogical perspectives and practices of high school Technology teachers in engineering design-oriented STEM courses. Specifically, the study focuses on teachers' educational beliefs, the curriculum design models they adopt, and the scaffolding and questioning strategies they employ during the engineering design process as informed by their noticing of students' learning states. By doing so, this study seeks to address gaps in existing research regarding teachers' pedagogical decision-making processes and to provide empirical evidence and practical implications for the design and implementation of engineering design-oriented STEM curricula.

2 METHODS

2.1 Research Methods and Processes

This study adopted a qualitative research design, employing semi-structured in-depth interviews to explore the pedagogical perspectives and instructional practices of high school Technology teachers in Taiwan within engineering design-oriented STEM courses. The interview protocol, which consisted of 14 questions, was constructed based on the research objectives and relevant literature. The research focused on three dimensions: (1) teachers' educational beliefs regarding engineering design-oriented STEM instruction; (2) the curriculum design models employed by the teachers; and (3) the learning scaffolds and questioning strategies used by teachers during the engineering design process.

The interviews were conducted online in a one-on-one format, with each session lasting approximately 60-90 minutes and being audio-recorded in full. The interview process began with the interview protocol to guide teachers in recalling and describing their educational beliefs, curriculum design, and the use of scaffolding and instructional strategies, followed by probing questions to further explore their perspectives when appropriate. The interviews were conducted by the researcher or by two trained research assistants, who also assisted with verbatim transcription. To ensure research reliability and validity, with participants' consent, the research team also invited teachers to provide relevant course materials from their engineering design-oriented project courses, which were used as supplementary data for triangulation during the analysis.

2.2 Participants

A total of 14 high school Technology teachers from various regions in Taiwan were recruited, all of whom possessed practical experience teaching engineering design-oriented STEM project courses. The cohort included both novice and veteran educators: at the time of the interviews, five participants had five years or fewer of teaching experience, while nine were teachers with six years or more of teaching experience. Prior to the interviews, the research purpose, data usage, and confidentiality principles were explained both verbally and in writing, and informed consent was obtained from all participants.

2.3 Data Collection and Analysis

In the data analysis process, an initial coding framework was first established based on the research structure, encompassing three primary axes: "Educational Beliefs," "Curriculum Design Models," and "Learning Scaffolding and Questioning Strategies," followed by initial thematic coding and inductive analysis. Subsequently, focusing on the "Scaffolding and Questioning Strategies" axis, the study further examined how teachers noticed students' critical performances and interpreted their understandings and difficulties through the three dimensions of teacher noticing (attending–interpreting–responding) (Jacobs et al., 2010). This was then integrated with the framework proposed by Walsh and Sattes (2011) to investigate the types of questions employed by teachers and analyze their timing of use within engineering design projects. Finally, through iterative comparison and integration, common patterns and variations across respondents

were synthesized to address the research objectives and formulate the study's findings and conclusions.

The researcher used ChatGPT 5.1 and Gemini 3 as supportive tools for ideas soundboarding, translation, and copy editing. Qualitative data analysis was first conducted using NVivo 12 software, including initial thematic coding and inductive analysis of 14 interview transcripts. NotebookLM was subsequently used as an analytical support tool to facilitate reflective comparison, assist in confirming preliminary analytic interpretations, and surface alternative analytical perspectives. The researcher then returned to NVivo 12 to further verify, refine, and confirm the analysis. All AI-suggested content was manually verified against the raw data. All final analytical decisions, interpretations, and manuscript text were produced by the researcher.

3 FINDINGS AND DISCUSSION

3.1 Educational Beliefs

Analysis of the Educational Beliefs dimension reveals a clear consensus among the 14 interviewed teachers that project-based learning is an instructional approach centered on real-world problem contexts or thematic issues, in which systematic processes (e.g., the engineering design process) are enacted to address problems. This approach emphasizes interdisciplinary integration and practical application, adopts a learner-centered orientation, and values the cultivation of student autonomy.

A deeper examination of teachers' beliefs in designing engineering design-oriented STEM project courses shows that, despite differences in emphasis across phases, teachers share a common goal of cultivating students' ability to apply interdisciplinary knowledge to solve complex problems. To this end, teachers focus on guiding students to systematically enact each stage of the engineering design process, including identifying "true problems" in project tasks, gathering relevant information, and applying science, mathematics, or technology (e.g., 3D modeling) to design experiments and collect evidence for prediction, analysis, and verification. These instructional beliefs align with Taiwan's recent Technology Education Curriculum Guidelines (Ministry of Education, 2018) and closely resonate with the seven central characteristics of integrated STEM proposed by Roehrig et al. (2021).

At the same time, teachers generally provide students with meaningful autonomy, valuing their agency and engagement throughout the project process. They emphasize collaborative learning based on students' strengths, prioritize the overall learning process over final products, and encourage learning through failure and iterative refinement.

Further synthesis of teachers' views on essential engineering design competencies indicates that problem scoping and predictive analysis are regarded as particularly critical. In addition, information gathering, modeling and testing, and optimization are identified as key design competencies. Skills such as communication, project planning and execution, hands-on technical skills, and process documentation and reflection are viewed as cross-cutting competencies that support learning across the entire curriculum. These findings are consistent with the research

themes and identified aspects of engineering practices synthesized by Kidd et al. (2025) in their review of K–12 STEM education studies.

3.2 Curriculum Design Models

The curriculum design models adopted by the teachers can be summarized into several key characteristics. First, in overall curriculum planning, most teachers employ a phased model that begins with foundational knowledge and skill development, followed by autonomous project implementation. During the first one-third to one-half of the semester, teachers arrange small-scale learning units or practice activities to strengthen students' prerequisite knowledge and hands-on skills, laying the groundwork for subsequent project work.

During project implementation, most teachers follow the systematic steps of the engineering design process. However, due to time constraints or differences in student characteristics, some teachers emphasize particular stages. A notable pattern is that most teachers provide a semi-structured, task-specific problem context without a single correct answer, enabling students to more readily identify design requirements and constraints. This approach reduces time spent on early problem identification and shifts instructional emphasis to idea development, modeling, analysis, testing, and optimization. In contrast, a smaller number of teachers offer broader thematic prompts, focusing on guiding students to analyze problem situations and gradually define problems and constraints independently.

Furthermore, many teachers design targeted instructional units for stages such as prototyping, predictive analysis, and experimental validation. These units emphasize completing design drawings and conducting modeling or simulation with simple materials or digital tools prior to fabrication, helping students identify potential design issues and examine solution feasibility. Such practices not only cultivate the use of theory- and data-based reasoning but also foster the habit of designing before making. As emphasized by English (2016) and Roehrig et al. (2021), making explicit connections between engineering design challenges and disciplinary knowledge is both challenging and essential, and students require effective instructional support to successfully integrate these concepts.

3.3 Learning scaffolding and questioning strategies

Overall, the learning scaffolds and questioning strategies employed by the interviewed teachers center on supporting students in clearly noticing and defining problems and applying knowledge for analysis and problem-solving. Specifically, when guiding students through the engineering design process, most teachers use self-designed instructional aids, 3D models, or exemplars of prior student work to help students more concretely understand project goals and task requirements.

Furthermore, teachers support systematic thinking and documentation through written learning portfolios or worksheets, which prompt students to complete specific tasks at each stage of the design process. These portfolios are generally aligned with the steps of the engineering design

process but provide only a structural framework for key elements, allowing students considerable autonomy in how they represent and document their design processes.

On the other hand, during project implementation, teachers primarily guide students through questioning in one-on-one or small-group interactions. An analysis of questioning strategies and their timing, informed by the attending–interpreting–responding framework (Jacobs et al., 2010), indicates that teachers mainly monitor students' learning states through classroom walkthroughs, attending to potential negative behavioral or emotional indicators such as confusion, ineffective group interactions, fear of failure, or passivity. At the same time, most teachers infer students' knowledge and skill mastery by observing the quality of students' self-initiated questions, their responses to teachers' follow-up questions, and the testing status of prototypes. Some teachers additionally rely on progress checkpoints or milestone reviews to identify learning challenges through regular reporting.

The analysis of how teachers interpret students' performances and difficulties in engineering design-oriented project courses can be summarized into four main dimensions: (1) insufficient practical skills; (2) limited understanding of the engineering design process; (3) difficulty adapting to open-ended problems; and (4) insufficient or weakly connected interdisciplinary knowledge. In response to these challenges, analysis of the interview data shows that teachers' questioning strategies, ranging from foundational troubleshooting to advanced reasoning and argumentation, exhibit the following key characteristics:

First, teachers primarily utilize iterative follow-up or guided questioning to stimulate students' thinking, rather than directly explaining problem causes or providing answers. For instance, Teacher J uses step-by-step guided questioning to help students identify why their designed linkage mechanisms fail to operate smoothly. These questioning strategies closely resemble Socratic questioning (Paul & Elder, 2007) and the "Probing Questions" proposed by Walsh and Sattes (2011), and are applied across different stages of the engineering design process. In the early stages of problem scoping and information gathering, probing questions guide students to decompose broad problems into actionable sub-problems and identify relevant information sources. During the middle stages, from solution development to modeling and testing, teachers use such questions to prompt students to identify emerging problems, anticipate potential challenges, and determine appropriate tools or directions for further inquiry, encouraging them to develop tentative solutions before consulting the teacher. Given students' frequent difficulties in locating usable and credible references, teachers further support information gathering by providing keyword prompts, offering multiple search channels, preselecting relevant resources, and requiring students to evaluate source credibility, thereby improving the quality of collected information. These instructional approaches closely align with the teaching strategies for supporting engineering design learning identified by Crismond and Adams (2012).

Secondly, teacher questioning also emphasizes strengthening interdisciplinary connections to integrate theory and practice. For example, Teacher E guides students to apply the "Ideal Gas Law" and "projectile motion" to calculate the thrust and initial velocity of an air rocket, comparing these values with actual launch data to analyze the discrepancy between theory and practice. The questioning strategies used for this purpose align with "Inference Questions" and "Interpretation Questions" proposed by Walsh and Sattes (2011) and are commonly applied during solution

development, predictive analysis, and testing and refinement, guiding students to engage in "if–then" reasoning. In particular, predictive analysis and modeling-based testing grounded in disciplinary knowledge represent key features that distinguish high school engineering design from middle school creative design (Ministry of Education, 2018). Accordingly, these questions prompt students to justify the feasibility of design solutions using theoretical principles, design experiments and identify key variables, predict the outcomes of design decisions, and construct evidence-based arguments based on test data. Moreover, the engineering design details emphasized by teachers during this guidance process closely resonate with the epistemic features of engineering practices highlighted in Simarro and Couso's (2021) work.

Finally, throughout the project implementation process, teachers use ongoing interactive questioning to check students' understanding of current design steps, thereby maintaining project momentum and progress. Teachers also provide timely prompts to draw attention to potential issues before students encounter major setbacks. During the optimization and reflection stages, teachers guide students to systematically refine their designs based on test results, engage in metacognitive reflection on the overall project process, and evaluate final outcomes. This practice aligns with the concepts of "Questions to Check for Student Understanding" and "Reflective Questions" proposed by Walsh and Sattes (2011). Overall, the iterative questioning strategies observed resonate with Wells's (2016) view of questioning as a central mechanism for eliciting students' "need-to-know" knowledge and advancing the engineering design process, thereby supporting higher-order cognition.

4 CONCLUSION

This study examined the educational beliefs of 14 high school Technology teachers, the curriculum design models they adopt, and the scaffolding and questioning strategies they use to guide student engagement in engineering design-oriented STEM courses. The findings reveal a shared belief that systematically engaging students in the engineering design process is essential for developing their ability to apply interdisciplinary knowledge to solve complex problems. In line with this belief, teachers commonly employ a phased curriculum structure that progresses from foundational skill development to inquiry-oriented, student-driven projects, supported by learning portfolios and related scaffolding strategies. Throughout the process, teachers use diverse and interactive questioning practices—including probing, inference, and interpretation questions—to stimulate student thinking, avoid providing direct answers, and strengthen connections between interdisciplinary knowledge and practice. Building on these findings, future research may explore the integration of emerging technologies (e.g., Generative AI) or examine engineering design-oriented STEM courses and questioning strategies at other educational levels.

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