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Exploring a Teacher's Discursive Moves in Facilitating Middle School Students' Epistemic Practices of Engineering

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Abstract

Integrating engineering into K-12 science classrooms is increasingly emphasized to enhance students' engagement with scientific and mathematical concepts through real-world problem solving. Teachers play an important role in supporting students' learning as they engage in engineering design. However, most research exploring teachers' implementation of engineering design activities and their engineering discourse has been conducted in whole-classroom settings. Little is known about how teachers facilitate students' engagement with epistemic practices of engineering (EPEs) during small-group work. This study investigates how a middle school teacher's discursive moves influenced students' engagement with EPEs within an integrated STEM unit. Using a qualitative case study approach, we analyzed teacher-student interactions over seven days as students engaged in brainstorming, planning, and testing design solutions. Data sources included video- and audio-recorded interactions and student artifacts. The findings revealed that while the teacher employed various discursive strategies—such as scaffolding, questioning, and providing scientific knowledge—there were missed opportunities to elicit student reasoning and address critical conceptual challenges. Notably, the teacher's guidance did not always align with students' emerging needs, limiting their ability to refine their designs. These findings highlight the need for professional development focused on responsive teaching strategies that foster deeper student engagement in engineering practices. This study contributes to the growing discourse on STEM education by identifying key pedagogical moves that can influence students' engagement with epistemic practices of engineering during engineering design activities.

Keywords: epistemic practices of engineering, teachers' discursive moves, engineering design activity, integrated STEM, small-group learning, engineering education, science education

Introduction

In the U.S., the growing emphasis on integrating engineering into science curricula has been highlighted in numerous national reports and research efforts, such as reports from the National Academy of Engineering (NAE) & the National Research Council (NRC; NAE & NRC, 2014; NRC, 2012) and the Next Generation Science Standards (NGSS Lead States, 2013). This emphasis on engineering education underscores the necessity for students to apply scientific, mathematical, and engineering principles to address real-world challenges (Roehrig et al., 2021; Moore, Glancy, et al., 2014). Additional arguments for engaging students in the engineering design process include the development and application of 21st-century skills, including collaboration, communication, creativity, and critical thinking (e.g., Roehrig et al., 2021; Moore, Stohlman, et al., 2014; NAE & NRC, 2014).

To optimize the intended benefits of engineering integration into K-12 science classrooms, it is critical to investigate how students engage in epistemic practices of engineering (EPEs). EPEs are defined as the specific ways members of a community propose, justify, evaluate, and legitimize knowledge claims within an engineering framework (Cunningham & Kelly, 2017; Kelly, 2008; Kelly, 2016). In K-12 classrooms, as students engage in these practices, they grapple with knowledge claims, develop understandings, and construct meaning through problem-solving experiences (Jin & Geslin, 2009; Kelly et al., 2017). Some examples of EPE indicators are developing processes to solve problems, considering problems in context, applying mathematics and science knowledge to problem-solving, constructing models and prototypes, and making evidence-based decisions.

Our prior research has highlighted significant variability in students' participation and engagement with these EPEs (Roehrig et al., in review). However, this prior work focused solely on student-to-student interactions in small-group engineering tasks and did not consider the role of the teacher. Given that teachers play a pivotal role in facilitating engagement in EPEs (e.g., Cunningham & Kelly, 2017; Jin & Geslin, 2009), the current study was guided by the following research question: *How does a middle school teacher's use of discursive moves facilitate students' engagement in epistemic practices of engineering (EPEs) during small-group engineering design tasks.* This study focused on scaffolding strategies and interaction techniques employed by the teacher to maintain student engagement in EPEs.

Theoretical Framework

This study is grounded in two interconnected frameworks – teacher discursive moves (Bansal, 2018) and epistemic practices of engineering (Cunningham & Kelly, 2017) – to explore how a teacher facilitates student engagement with EPEs during small-group engineering design tasks. These frameworks provide a robust lens for examining the interplay between teacher moves and student engagement with EPEs during engineering design challenges within an integrated STEM activity.

Teacher Discursive Moves

Classroom talk is an essential component of effective teaching, especially in STEM education, where it supports students in developing conceptual understanding, critical thinking, and problem-solving skills. Research has long recognized structured patterns in teacher-student interactions, such as the Initiation-Response-Evaluation (IRE) model (Mehan, 1979) and its variant, Initiation-Response-Follow-up (IRF; Sinclair & Coulthard, 1975). These triadic dialogue patterns typically involve the teacher initiating a question, the student responding, and the teacher either evaluating or following up. While these structures are widely used, they have been criticized for their teacher-centered nature, which can limit opportunities for students to engage deeply with the material or express their own ideas (Lemke, 1990; Michaels & O'Connor, 2013). Scholars have suggested that the "follow-up" move in IRF sequences could be adapted to foster student learning by prompting deeper exploration and scaffolding understanding through iterative exchanges (Chin, 2006; Mortimer & Scott, 2003). Open-ended chains of dialogue, where teacher prompts and student responses build on one another, provide greater interactivity and allow students to explore diverse perspectives (Mortimer & Scott, 2003).

The concept of dialogic discourse, rooted in Bakhtin's (1981) work, offers a contrasting approach to traditional authoritative discourse. The dialogic discourse emphasizes reciprocal exchanges, where students and teachers collaboratively construct knowledge by sharing, questioning, and refining ideas. Unlike monologic interactions that focus on transmitting a singular perspective, dialogic teaching creates opportunities for students to engage critically and consider multiple viewpoints (Alexander, 2001; Teo, 2016). Research shows that such approaches can foster collaborative reasoning, critical thinking, and a deeper understanding of complex concepts (Mercer & Littleton, 2007). However, achieving dialogic discourse in classrooms remains challenging, as many teachers lack the strategies or confidence to implement it effectively (Michaels & O'Connor, 2013). Professional development initiatives, such as the Thinking Together program (Mercer & Littleton, 2007) and epiSTEMe (Ruthven et al., 2017), have aimed to address these challenges by equipping teachers with tools for dialogic teaching. While these efforts have shown promise, they underscore the need for sustained support to help teachers integrate dialogic practices into their classrooms consistently.

Building on these ideas, Bansal (2018) proposed a framework to categorize teacher discursive moves that can foster dialogic discourse and enhance student engagement. The framework identifies five different discursive move categories: setting the stage: baseline assessment, pushing to make thinking explicit, encouraging wider responses, talk organization, and modeling problem solving. Each category is further divided into several observable and actionable subcategories. Table 1 provides a comprehensive overview of Bansal's teacher discourse moves.

Table 1

Codes for Teachers' Dialogic Discursive Moves

Category and its Description	Subcategory	Codes
1. Setting the stage: Baseline assessment These moves: gauge understanding of pre-requisites by drawing out what has been taught in previous classes and grades; facilitate connections between present and past shared experiences; entail critical examination of students' everyday perspectives by eliciting their experience on probes emanating from daily life; and ascertain current levels of	Eliciting experiences	EIEx
	Gauging understanding of pre-requisites	PreQ
	Focusing attention on previous work	FocP
	Asking for factual knowledge	AsFK

conceptual development to identify what needs to be developed further	Generating ideas	GI
2. Pushing to make thinking explicit These moves encourage students to: make explicit their thought processes using a variety of ways, such as, elaborating, using explanations, justifications and reasons in support of one's arguments; make connections between scientific concepts and extend similar justifications in related circumstances; use skills of hypothesizing possible solutions, testing for evidence, and analyzing events to logically arrive at conclusions backed by evidence	Asking for extension of the concept	Ext
	Asking for justifications	Jus
	Asking for predictions	Pre
	Asking for elaboration	Elb
	Asking for a way to test or find out	AskT
	Asking for inferences	AsI
3. Encouraging wider responses These moves are used to: invite students to take a position; author accounts so that students own responsibility for their talk; position students' accounts in relation to each other to develop coherence in dialogue; promote meta-talk so that students reflect on their reasons and views before sharing them with the rest	Asking authentic questions that invite students to take a position	AQ
	Making explicit invitations	ExIn
	Authoring accounts	AuthA
	Positioning accounts	PosA
4. Talk Organization Teachers use these moves to: provide scientific canonical information that could steer the direction of the discourse towards established scientific views; provide clarification of curricular objectives achieved through the lesson; reformulate key arguments developed during lessons; rephrase students' comments, questions, observations; build the scientific story using learners' inputs/arguments/reasoning.	Reformulation	Ref
	Rephrasing student's questions/statements/ comments	ResQ
	Providing scientific canonical knowledge	ScK
	Building upon learner's previous argument	Sarg
	Clarifying learning objectives	CILO
5. Modeling Problem-Solving Strategies Teachers use these moves to: demonstrate problem-solving strategies to students by providing them mental models such as seeking points of view, comparing them using reasoning, providing and accepting criticism constructively and working towards joint intellectual endeavors; provide hints/suggestions that serve as cues in scientific meaning making	Asking for opinion	AskOp
	Handling agreements/ disagreements	AgrD
	Developing consensus	Dcons
	Asking for application of content knowledge	Appl
	Cueing	Cue

As Michaels and O'Connor (2013) noted, achieving dialogic discourse in classrooms remains challenging, particularly in whole-class settings where interactions are often constrained by time and the large number of students. However, dialogic discourse may be more feasible in small-group teacher-student interactions, where the intimacy of the setting allows for deeper engagement and individualized support. Therefore, this framework is well-suited for the context of this study to analyze how teachers facilitate student engagement with EPEs during small-group engineering activities.

Epistemic Practices of Engineering

Epistemic practices represent the ways individuals within a disciplinary community engage with knowledge–proposing, evaluating, and legitimizing claims through interaction and shared norms. Knorr Cetina (1999) described these practices as central to knowledge production, or how people construct meaning and solve problems. Within the K-12 context, Kelly (2008) defined epistemic practices as the specific methods through which learners justify and critique knowledge claims, often in collaborative and problem-solving settings. These practices are deeply social, relying on communication and discourse to shape collective understanding. For instance, teamwork and problem-solving activities contribute to the development of disciplinary norms, emphasizing the importance of shared values and interaction in learning processes (Roth, 2014).

In engineering education, epistemic practices are integral to students' engagement with design tasks and problem-solving processes. Cunningham and Kelly (2017) characterized these practices, referred to as EPEs, as encompassing both theoretical and procedural knowledge. These practices enable students to navigate the iterative nature of engineering design, balancing creativity with the constraints of real-world problems.

Research has shown that engaging students in EPEs not only enhances their understanding of engineering concepts but also shapes their identity as problem-solvers. For example, Kelly et al. (2017) demonstrated that when teachers explicitly named students' actions as engineering practices and addressed them as engineers, it reinforced their sense of agency and belonging within the discipline. Despite these findings, much of the existing literature has focused on whole-class interactions, leaving a gap in understanding how small groups engage with EPEs during collaborative design activities.

Our previous research (Roehrig et al., in review) addressed this gap by exploring how students engaged in EPEs during small-group engineering design tasks. Roehrig et al. (in review) refined Cunningham and Kelly's (2017) EPE framework to better capture the nuances of the small-group engineering design task. Table 2 presents the adapted framework, which was used to analyze student interactions throughout the engineering design process. The findings showed that students engaged with certain EPEs on different days of the unit during the distinct stages of the engineering design challenge. However, one limitation of that study was its lack of focus on the teacher's role in activating and supporting students' engagement with EPEs.

Table 2
Codes for Epistemic Practices of Engineering

Practice	Code	Observable characteristics
Criteria and constraints	CC	Taking criteria and constraints into account during design process
Problems in context	CTXT	Recognizing the context of the problem
Trade offs	TOFF	Optimizing design by comparing criteria against constraints
Assessing a design solution	ADS-cc	Assessing solution based on set criteria and constraints
Assessing a design solution	ADS-msknow	Assessing solution based on applying math/science knowledge
Learning from design failure	LFDF	Using test information to move a failed design forward
Evidence-based decisions	EBD	Using evidence to make decisions based on available data
Iterative design refinement	IDR-diag	Refining ideas through iterative-reflective cycles, diagnostic troubleshooting
Iterative design refinement	IDR-tweak	Refining ideas through iterative-reflective cycles, tweaking for minor adjustments
Applying mathematics and science knowledge	MSKNOW	Using mathematics/science concepts or principles to propose, test, or explain design solutions
Evaluating multiple solutions	MSOL	Evaluating multiple solutions against each other
Systems Thinking	SYST	Considering how component parts of a system work together and over time
Developing models	MODL	Developing a plan before building or testing a prototype before scaling up; includes physical, mental, virtual models
Building prototype	PROTO	Building prototype with intent to test model
Envisioning multiple solutions	ENVSN	Brainstorming different possible solutions
Innovating processes, systems, and designs	INNV	Pushing boundaries; applying creativity with respect to materials or design elements
Considering Materials and their Properties - Test/Evaluate	MTRL-TE	Testing or exploring properties of materials
Considering Materials and their Properties - Connect to Design	MTRL-CON	Connecting materials and their properties to the design problem

Building on this research, the present study examines how teacher discursive moves are related to student participation in EPEs during small-group engineering tasks. By analyzing these interactions, this research aims to uncover strategies for fostering deeper and more meaningful engagement with engineering practices in K-12 classrooms, especially in middle school.

Methods

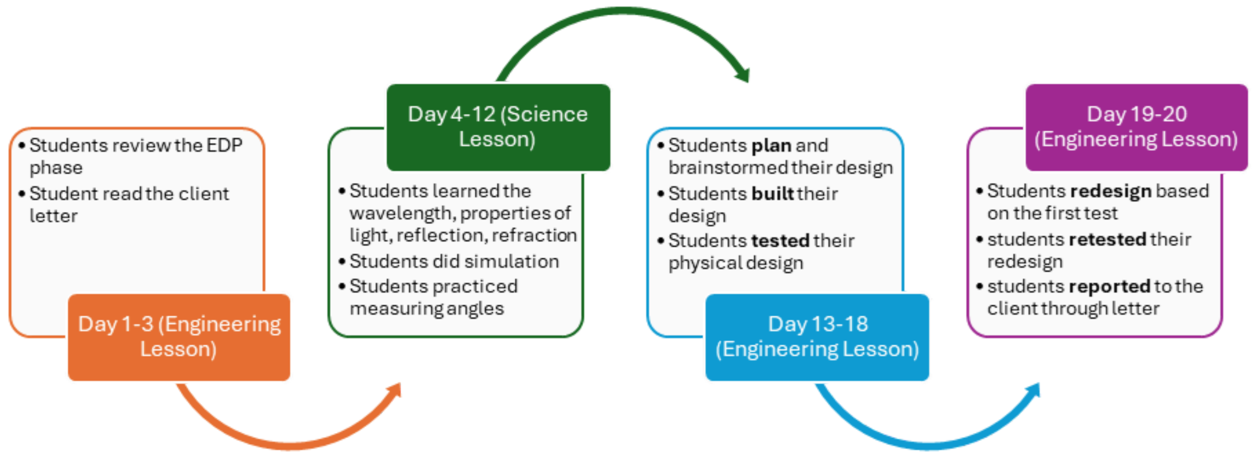
This study examined the role of a middle school teacher in facilitating students' engagement with epistemic practices of engineering (EPEs) within a small group during an integrated STEM activity. A qualitative case study design (Merriam, 1998) was employed to explore the teacher's strategies for supporting students' engagement with EPEs in this collaborative setting. Specifically, a single case study approach (Yin, 2014) was utilized to observe and analyze the interactions between the teacher and a group of four students during an integrated STEM unit. This design provided a rich, context-specific exploration of the teacher's facilitative role and the ways in which the students applied EPEs in their collaboration.

Context

This study centers on the role of a middle school teacher in facilitating student engagement with EPEs during an integrated STEM unit. The study was conducted as part of a professional development for science teachers, aimed at deepening their understanding and application of integrated STEM teaching strategies. During the summer professional development program, teachers learned about integrated STEM instruction using a specific integrated STEM curriculum designed to integrate science, mathematics, and engineering concepts and grounded in the frameworks for integrated STEM and quality K-12 engineering education (Moore, Glancy, et al., 2014; Moore, Stohlman, et al., 2014). In this paper, the focus is on one teacher's implementation of the "Laser Security System" (LSS) unit.

The LSS curriculum required students to apply their knowledge of science and mathematics, including light properties and geometry, to design a laser security system aimed at protecting artifacts from theft in a traveling museum. The design challenge involved using a single laser beam that must be refracted and reflected at least once, with the system needing to ensure that a potential thief would cross the laser beam three times to reach any artifacts. The curriculum was structured across 20 days (see Figure 1), with this study focusing specifically on the engineering lessons during the final seven days of the unit.

Figure 1
Overview of the Laser Security System Curricular Unit



Participants

For this study, the implementation of the LSS unit by one teacher, Jason (a pseudonym), was explored. Given the exploratory nature of this research, the analysis focused on the interactions of the teacher with one small group, consisting of Alex, Ben, Daniel, and Cameron (all pseudonyms and all white males). The teacher, students, and students' parents/guardians provided informed consent and assent to participate in the study.

Data Collection and Preparation

In this study, the primary data were collected through video and audio recordings. Since the primary focus was to analyze how a teacher facilitates students' engagement with EPEs within small groups, a video camera was positioned near the students' group, and an audio recorder was positioned in the middle of the group's table. These devices recorded all LSS lessons from day 1 to day 20, although the analysis focused on engineering tasks conducted from day 13 to 20. Along with primary data, secondary data, such as videos of whole-class lessons, field notes, and students' work artifacts, were collected to provide context for analysis.

Data Analysis

After data collection, all small group recordings, specifically the interaction between students and teachers, were transcribed. The transcriptions were organized into a spreadsheet, which included timestamps, spoken words, and a description of relevant gestures.

The data analysis was conducted in three phases to provide a comprehensive understanding of how the teacher facilitated students' engagement with EPEs during an integrated STEM activity. This multi-phase approach ensured a nuanced and holistic exploration of the teacher's interaction with the group.

At the first phase of analysis, we conducted an independent iterative examination of each utterance within the teacher-student interactions. This process involved coding both dialogic and gestural discourse from the transcripts to identify key teacher supports and actions. Three researchers independently coded the data using two frameworks: teacher discursive moves (Table 1; Bansal, 2018) and EPEs (Table 2; Roehrig et al., in Review). This independent coding phase allowed for diverse perspectives to be applied to the data, enhancing the depth and breadth of the analysis.

During the first phase of analysis, it became evident that certain teacher moves were not adequately captured by the existing codes/frameworks. Therefore, to address this limitation, we introduced additional codes to both the teacher discursive moves framework and the EPE framework.

For the teacher discursive move framework, we introduced four additional codes: *Providing Contextual Knowledge and Facts (ScK-C), Giving Directions (Dir), Generic Check-In (GenCheck),* and *Pacing Check (PaceCheck).* The *ScK-C* code was used to capture instances where the teacher provided contextual information, such as criteria and constraints, consideration of a museum setting, and the goal of detecting a thief. The *Dir* code, on the other hand, was applied to moments where the teacher provided step-by-step instructions, guiding students on specific actions required to complete their tasks. While the *GenCheck* was used for instances where the teacher checked in with students to see how things are going generally, the *PaceCheck* was applied to moments where the teacher checked in with students to see where they are at.

For the EPE framework, we introduced two additional codes: *Optimizing Design (OPT)* and *Teacher Developing Model (MODL-T).* The *OPT* code was used to capture instances where the teacher encouraged students to optimize their design. The *MODL-T* code, on the other hand, was used to capture situations where the teacher took over the process of developing a model. In other words, the teacher performed the task for the students.

At the second phase of analysis, all coded transcripts were reviewed collaboratively in regular consensus meetings. The primary purpose of these meetings was to ensure consistency, reliability, and validity in the application of codes across all utterances. During these discussions, the researchers reconciled discrepancies across their individual coding, refined coding decisions, and documented key teacher supports and actions that emerged during interaction with students. This whole process not only strengthened the reliability of the findings but also provided a richer understanding of the teacher's role in facilitating students' engagement with EPEs.

Finally, in the third phase of analysis, the impact of the teacher's discourse moves on students' engagement with EPEs was determined by reviewing the behavior and discourse of the group after the teacher left to interact with another small group. This approach allowed for an evaluation of how teacher interventions influenced subsequent student activities and their engagement with specific EPEs. Notably, the students' discourse had already been coded as part of prior work (Roehrig et al., in review) which provided a robust foundation for understanding the dynamics of student engagement. By aligning the teacher's discursive moves with the coded student discourse, this phase of analysis ensured a comprehensive understanding of the teacher's support of students' engagement with EPEs.

Findings

The findings are organized into four subsections to provide a comprehensive analysis of teacher support across the engineering design process. The first subsection examines the overall timeline of teacher support across the three design phases. The subsequent subsections delve into a qualitative exploration of teacher support within each specific phase: brainstorming, planning, and testing. To deepen the understanding of how teacher support facilitated students' engagement with EPEs, illustrative excerpts from classroom interactions are also included. These examples provide rich contextual insights into the nature and impact of teacher moves during each phase.

Overview of Teacher Support Across Engineering Design Phases

Table 3 provides an overview of teacher interactions with the group across the three phases of the engineering design process: brainstorming, planning, and testing. Table 3 highlights the total time spent by the small group during each phase of the engineering design process and the frequency of teacher interaction with the group. Notably, teacher interactions were limited during the brainstorming and planning phases, with only one interaction recorded on Day 13 and Day 15, respectively. In contrast, the testing phase exhibited a higher frequency of teacher support, with four interactions distributed across Days 17, 18, and 19.

Table 3

Overview of Teacher Interaction with the Group Across Engineering Design Process Phases

Engineering Design Process Phases	Day	Total Time (min:sec)	Frequency of teacher interacted with the group
Brainstorming	Days 13 and 14	41:57	1
Planning	Days 14 – 16	40:16	1
Testing	Day 17 – 19	70:48	4

Teacher Support During the Brainstorming Phase

During the brainstorming phase, the teacher provided limited direct support to the small group, with a single interaction occurring on Day 13. On this day, the students were tasked with reading the client letter and developing an understanding of the client's needs. By the time the teacher engaged with the group, the students had already completed this initial task. Shortly after the students completed the initial task, the teacher approached the group to check their progress, as documented in Table 4.

Table 4

Example of Teacher Support During the Brainstorming Phase on Day 13

Line	Time Stamp	Speaker	Dialogue [and gestures]	Discursive Moves Codes	Teacher's EPE Codes
1	19:09 - 19:15	Teacher	What are you on right now? Did you read the client's letter response?	PaceCheck	CC, CTXT
2	19:16	All Students	Yes		
3	19:16	Teacher	You did?		
4	19:17	All Students	Yeah		
5	19:18 - 19:21	Teacher	Where did that go? Did you put the paper back?		
6	19:21	All Students	Uhm..		
7	19:22 - 19:24	Teacher	Now what is the next step in the process?	AsFK	
8	19:24 -19:25	All Students	Brainstorming design		
9	19:25 - 19:31	Teacher	Okay. How many designs do you need to come up with? Individually?	AsFK	ENVSN
10	19:32	Ben	Three		
11	19:33 - 20:08	Teacher	Three individuals. Think of all different factors, and you want to make all different. Okay. So, right now, you are coming up with individual ones. Once you are finished, you are gonna have the group collab, okay. Then, you are gonna have that remix. But to get to that remix, you are gonna start documenting three things. You have about 12 minutes left of this. And you got to have it probably... Our goal would be to have three down and we'll start a collaboration. Okay? So that's our goal.	ResQ GI Dcons	ENVSN ENVSN ENVSN

The teacher’s interaction focused on ensuring the students were on track and engaging with the required activities after understanding the client letter (Line 1). When the students affirmed their completion of the task (Lines 2 and 4), the teacher shifted focus to the next steps by *asking for factual knowledge (AsFK)* (Lines 7 and 9). The interaction progressed as the teacher gave directions to the students to brainstorm individual design ideas.

The teacher emphasized the importance of generating three unique designs, incorporating different factors, and preparing for group collaboration to come up with a consensus design (Line 11). This mirrored the teacher's instruction at the beginning of the classroom to the whole class. However, the teacher used colloquial language related to criteria, constraints, and coming up with a consensus design. In line 11, the teacher directed the students to consider “all different factors” when creating their individual designs. This aligns with the teacher’s earlier whole-class instruction, when the teacher provided explicit guidance on incorporating the criteria and constraints. For example, at the beginning of the classroom, the teacher stated, “So to protect the artifact, the thief needs to cross at least three times. So those are your must haves, okay!” (4:12 - 4:23) and added, “Now, some constraints that are going to be different for your designs. So the limitations are materials, budget, and after you read the letter, it is going to give more detail about the constraints pertaining to the artifacts” (4:24 - 4:59). Additionally, the teacher mentioned “group collab” and “remix” in Line 11. These words also refer to the teacher’s earlier whole-class instruction. During the whole-class session, the teacher instructed, “When you're finished with all of everybody generating your ideas, have a group discussion, decide on one design.” (7:12 - 7:20). Here, “group collab” refers to “group discussion,” while “remix” refers to “decide on one design.” Both phrases emphasized the importance of group collaboration in reaching a consensus design. During the whole-class instruction, the teacher emphasized considering criteria and constraints, generating three individual designs, and engaging in group collaboration to come up with a consensus design multiple times. This continuity between the whole-class instruction and the small-group interaction likely reinforced students’ understanding of their tasks and expectations during the brainstorming phase.

The directive in Line 11, anchored in the earlier whole-class instruction, prompted the students to engage in multiple EPEs during the brainstorming phase. For example, after the teacher emphasized that students needed to come up with three individual designs (Line 11), the students engaged in *envisioning multiple solutions (ENVSN)*. They returned to their individual drawings, and when Ben explained the merits of his design to the group, Cameron reminded him that each individual student needed to propose three designs. Ultimately, the teacher’s reminder about coming up with multiple designs led to the students spending approximately 6.5 minutes on brainstorming across Days 13 and 14. Similarly, the teacher's instruction to consider all criteria and constraints triggered the students to *assess a design solution based on criteria and constraints (ADS-CC)* and *recognize the context of the problem (CTXT)*. Furthermore, the encouragement to collaborate and choose a consensus design led the students to engage in *evaluating multiple solutions (MSOL)*.

Teacher Support During the Planning Phase

During the planning phase, teacher support was similarly limited, with a single interaction occurring at the beginning of Day 15. On this day, the students were tasked with developing a detailed blueprint that included labels, angles, and their consensus design (see Figure 2 for their final consensus design). While the students had already established their consensus design, they initially struggled with determining accurate angles between laser lines. Despite the teacher spending the first 7 minutes and 19 seconds during the whole-class instruction showing the students on how to measure the angle, the students still struggled. Early in the group discussion, Alex called the teacher over and asked, “So how do you find out where to put the mirror?” (1:23–1:27). In response, the teacher joined the group to address Alex's question. The complete interaction in response to Alex's question is detailed in Table 5.

Figure 2
Reproduction of Group's Consensus “Double M” Design

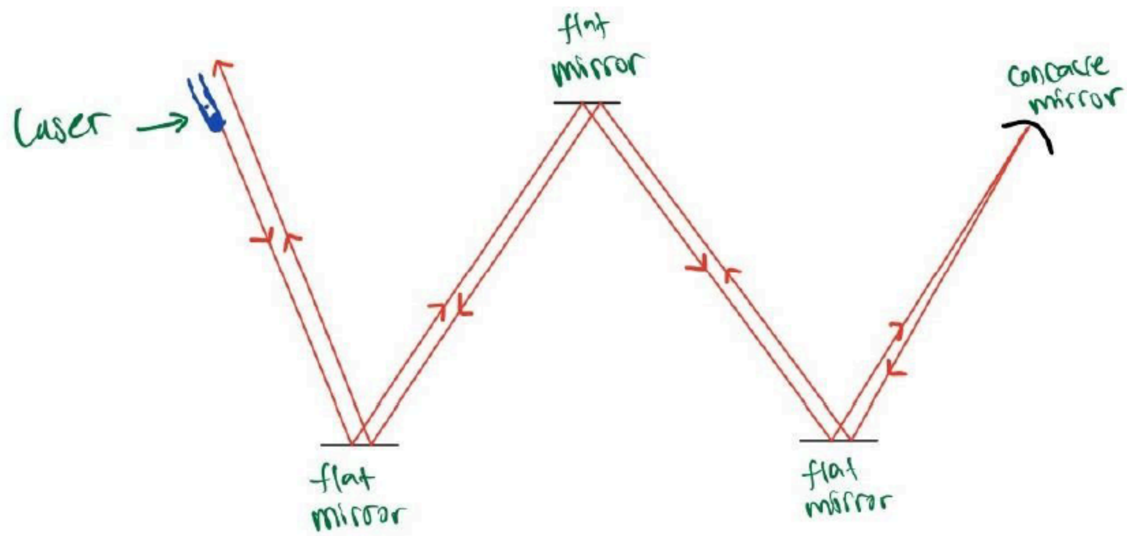


Table 5
Example of Teacher Support During the Planning Phase on Day 15

Line	Time Stamp	Speaker	Dialogue [and gestures]	Discursive Moves Codes	Teacher's EPE Codes	Student's EPE Codes
1	1:21 - 1:23	Teacher	Work with your group [The teacher is coming to their table and instructing Ben to come back and work with his group]			
2	1:23 - 1:27	Alex	So how do you find out where to put the mirror?			MSKNOW
3	1:27 - 1:29	Teacher	What angle to put the mirror at?	ResQ		

4	1:29	Alex	Yeah.			MSKNOW
5	1:30 - 1:37	Teacher	So, to figure that out, wherever the laser is starting, is it starting here?	AsFK		
6	1:37	Alex	Yeah.			MSKNOW
7	1:38 - 2:10	Teacher	So it's going to hit a convex mirror and then reflect. Okay, so whatever this whole angle is, okay, halfway through is going to be where that normal line is, okay. And from the angle of incidence and normal line, that's going to be 90 degrees, okay. So you're going to use your protractor and measure 90 degrees minus this angle, okay...	DIR, ScK	MSKNOW, MODL(T)	
8	2:11	Alex	Oh.			MSKNOW
9	2:11 - 2:37	Teacher	And that's going to be along this line. So, in doing so, [gets a protractor from Alex and uses it to measure the angle], what's this angle? It's along 0, it's at 45. So if that angle is 45, then 22 and a half, if my math's correct. So what's 90 minus 22 and a half?	ScK, AsFK	MSKNOW, MODL(T)	
10	2:37 - 2:38	Ben	68			MSKNOW
11	2:41 - 2:58	Teacher	So 68 is what you're looking for that this line is going to be on, so that's 65, 66, 67, and 68. [turns to Ben] Is it going to be 67 and a half?	ScK, AsFK, ResQ	MSKNOW, MODL(T)	
12	2:58	Ben	[nods]			MSKNOW
13	2:59 - 3:00	Teacher	Because it's 22 and a half, right?	ScK, AsFK	MSKNOW, MODL(T)	
14	3:00	Alex	Yeah.			MSKNOW
15	3:01 - 3:10	Teacher	So it's going to be a little less, it's gonna be more towards 67, not 68, OK. So you see what that is?	ScK, AsFK	MSKNOW, MODL(T)	
16	3:09	Alex	Yeah.			MSKNOW

17	3:11 - 3:25	Teacher	And then this is the angle because 22 and a half plus 90 is, should be 12 and a half. So whatever this angle should be, 90 minus that angle and 90 plus this angle should be this [turns to Alex].	ScK	MSKNOW, MODL(T)	
18	3:26	Alex	OK.			MSKNOW
19	3:27 - 3:31	Teacher	Does that make sense?	PreQ		
20	3:28	Alex	Yeah. [starts erasing, holding protractor]			MSKNOW
21	3:28 - 3:31	Teacher	That will help you out in drawing that line. [Teacher leaves the table; Alex continues to draw, measure, etc.]			

The teacher's approach to addressing Alex's question relied heavily on lower-level discursive moves, specifically explicit instruction on how to measure the angles. Instead of facilitating student-led exploration, the teacher *modeled the process (MODL[T])* by providing step-by-step guidance. This included the use of *Scientific Canonical Knowledge (ScK)* and *Asking for Factual Knowledge (AsFK)* related to mathematical operations. For example, the teacher demonstrated how to measure an angle using a protractor, offering precise instructions and calculations.

The teacher's explicit instruction and modeling of step-by-step guidance did facilitate the students' engagement with EPEs: *applying mathematics and science knowledge to their design (MSKNOW), and independently developing their design (MODL)*. Once they understood how to measure the angle, the students spent 14 minutes 38 seconds drawing the blueprint and accurately labeling the angles.

Teacher Support During the Testing Phase

During the testing phase, teacher support was more frequent compared to the brainstorming and planning phases. The teacher interacted with the students on four occasions: once on Day 17, twice on Day 18, and once on Day 19.

Teacher Interaction on Day 17

On Day 17, the group had completed their blueprint and received approval to proceed to testing. The teacher's interaction with the group on Day 17 (see Table 6) focused on *assessing* the students' consideration of *the client's criteria and constraints in their design and the context of the problem* (placement of the artifacts in a museum).

Table 6
Example of Teacher Support During the Testing Phase on Day 17

Line	Time Stamp	Speaker	Dialogue [and gestures]	Discursive Moves Codes	Teacher's EPE Codes	Student's EPE Codes
1	15:38 - 15:58	Teacher	Has the robber entered the door yet?	Cue	CTXT	
2	15:58 - 15:09	Ben	No, so, door [picks up robber and walks it] one, two, three…			ADS-CC, CTXT
3	16:10	Teacher	Where's the artifacts?	AsFK	CTXT	
4	16:12 - 16:14	Ben	[points to last 'wall'] They're all there.			CTXT
5	16:14 -16:19	Teacher	Oh there? So one, two, three [counting and pointing the laser beams]. Would you be able to put an artifact there? [pointing between the V of the second and third beam]	ResQ, Pre	ADS-CC	
6	16:20	Ben, Cameron, and Daniel	No…			ADS-CC
7	16:21	Ben	We could...			ADS-CC
8	16:23 - 16:24	Teacher	Would you put an artifact here? [points to corner of second and third beams]	Pre	ADS-CC	
9	16:25	Ben, Cameron, and Daniel	No…			ADS-CC
10	16:26	Teacher	Could you put one here? [corner of first and second]	Pre	ADS-CC	
11	16:27	Ben, Cameron, and Daniel	No			ADS-CC
12	16:28 - 16:36	Teacher	Good, so think now, how can you maximize your artifact protection? Or maybe think of how could…	AskT	ADS-CC, CTXT	

13	16:36 - 16:40	Ben	Well, we could put one here [pointing between the V of the second and third beam] if we could get this to come back like we originally wanted.			ADS-CC, TOFF
14	16:42 - 16:45	Teacher	Is this all the materials you've used? So you've got the mirrors? Right?	AsFK		
15	16:47 - 16:49	Ben	Well, we need one lens.			CC
16	16:50 - 16:51	Teacher	Why would you need a lens?	AsFK, Cue	CC	
17	16:52 - 16:53	Ben	We need one lens.			CC
18	16:54 - 17:02	Teacher	What's that for? I'm asking you. Why would having a lens be important?	AsFK, Cue	CC	
19	17:03 - 17:12	Ben	I don't know, because we're having trouble with this [concave] mirror because when it comes off this, it's curved, so it goes in different areas.			MTRL-CON
20	17:15 - 17:20	Cameron	Yeah, it moved; it's pointing here; it's pointing out there.			ADS-MSKNOW
21	17:24 - 17:26	Teacher	Hmmm… so what I've got to say is this: what does your design have to do?	AsFK, Cue	CC	
22	17:28 - 17:29	Ben	It has to protect artifacts			CC
23	17:30 17:32	Teacher	Okay, so it protects artifacts, what else does it have to do?	ResQ, Cue	CC	
24			[Teacher walks away]			
25	17:50 onwards		[More adjustments of the concave mirror to get the "Double M" design to work]			IDR-Tweak

During this first interaction, the teacher initially posed a question (Cue) that prompted the students to assess their design with respect to a robber entering the room. The teacher then posed multiple questions about alternative artifact placements. Although the students provided correct responses (Lines 6, 9, and 11), they were not prompted to elaborate on their reasoning. This represented a missed opportunity for the teacher to encourage students to articulate their rationale—that the artifacts could not be placed in certain locations because a thief could potentially access them without encountering three laser beams, thus failing to meet the criteria and constraints. Because the teacher did not ask for reasoning, the boys' primary design dilemma is not revealed (how to get the light to reflect back from the concave mirror to create the "double M" design).

The teacher then shifted focus by asking how the group could maximize artifact protection (Line 12). Ben responded in Line 13 by bringing up an issue the group was facing: the challenge of using the concave mirror to create the "double M" design work (refer to Figure 2 for their consensus design). The students were attempting to optimize their design by using a concave mirror to reflect the light back through the museum, meaning the thief would need to cross the laser beam eight times (see Figure 2). Here, they engaged with *optimizing design by comparing criteria and constraints (TOFF).* However, they struggled to redirect the reflected beam to the intended path due to the curved nature of the concave mirror. In their attempts, the students treated the concave mirror as a flat mirror, but they faced difficulty in striking the center of the concave mirror. They asked for guidance on addressing the challenge on how to use the concave mirror. However, the teacher did not respond to the students' concerns. As a result, an opportunity was missed to help the students optimize their "single M" design to be a "double M" design, as well as helping them to understand the interaction of light with a concave mirror.

Instead, the teacher redirected the conversation to another question related to the criteria and constraints, specifically about their use of materials to optimize their design (Line 14). When Ben responded, "Well, we need one lens" (Line 15), the teacher followed up with a series of Cue moves (Lines 16, 18, and 21) to prompt the students to restate the criteria and constraints and recognize that their design needed to include refraction in addition to reflection. However, in Line 19, Ben answered that he "do not know" why they needed a lens. Interestingly, he added, "because we're having trouble with this mirror because when it comes off this, it's curved, so it goes in different areas." This statement indicates that Ben, epistemically, was still thinking about the concave mirror–the challenge they were facing–rather than the lack of refraction in their design. Although Ben indicated that they were struggling with the concave mirror, again, the teacher continued asking about the lens instead of addressing the students' concern. The teacher continued probing with questions such as, "What does your design have to do?" (Line 21) and "What else does it have to do?" (Line 23). These questions aimed to guide the students to remember that incorporating a lens would meet an additional design criterion—specifically, that the design should involve at least one refraction. However, the teacher again failed to recognize the students' need for support in understanding the behavior of light with the concave mirror.

The teacher walked away without summarizing or concluding the discussion (Line 24). At this point, instead of adding a lens to their design, the students kept tweaking the mirrors and went back trying to make their "double M" design work. After they did minor tweaking to their mirrors, Ben said, "Okay, hold on, it protects bro... [counting beams robber pencil crosses] one, two, three, four… technically, back here this counts as six because it's going back again" (17:55–18:50). Ben assessed how many lines the robber would cross with the "double M" design *(ADS-CC* and *ADS-MSKNOW)*. After they realized that "double M" design would work, Cameron concluded, "No, you know what it needs to do, both of these [refer to the concave mirror and flat mirror] need to be tilted back a bit, that's why it's not going; that's the only thing, tilt it back a bit." At this point, they understood that if the mirror is tilted correctly, it will go all the way back, making their "double M" design work. In this moment, they engaged with *considering how component parts of a system work together (SYST)* and *using test information to move a failed design forward (LFDF).* While this did move the design forward, the students missed an opportunity to refine their design to address the criteria and constraints by incorporating a lens to meet the refraction design requirement and also missed an opportunity to understand how light interacts with a concave mirror which would have facilitated making their "double M" design work.

Teacher Interaction on Day 18

On Day 18, the teacher revisited the group to follow up on the Day 17 interaction (see Table 7). During this interaction, the teacher employed one discursive move code, *Providing Scientific Canonical Knowledge (ScK),* and one EPE code, *Connecting Material and Their Properties to the Design* (*MTRL-CON),* to explain the properties of the concave mirror and lens. The teacher attempted to connect these properties to the group's design but, potentially introduced misconceptions and used non-scientific language that could mislead the students.

Table 7
Example of Teacher Support During the Testing Phase on Day 18

Line	Time Stamp	Speaker	Dialogue [and gestures]	Discursive Moves Codes	Teacher's EPE Codes
1	7:41-7:46	Teacher	So with this laser, so when I hit this [points to concave mirror] you see how it shines? you see how the laser beam is spread out?	ScK	MTRL-CON
2	7:46- 8:00	Teacher	As I bring it, shine it at the lens, as I bring it closer to that, see how it focuses towards center and then it starts spreading out more?	ScK	MTRL-CON
3	8:00-8:09	Teacher	So what happens is, is, that light's coming in and it's at a curve, it's basically spreading and crossing.	ScK	MTRL-CON
4	8:10-8:15	Teacher	So what you're going to have to do is, this mirror just like the lens is bending the light rays.	ScK	MTRL-CON
5	8:15-8:20	Teacher	Okay, see how it's spreading out the light rays?	ScK	MTRL-CON
6	8:20-8:22	Teacher	You put a lens in front of it, it's going to counteract that	ScK	MSKNOW, MTRL-CON

7	8:22-8:25	Ben	Oohh!
8	8:25-8:27	Ben	Daniel, we just figured it out!

For instance, in Lines 1, 2, 3, and 5, the teacher demonstrated the behavior of light reflecting off a concave mirror. Instead of explaining that a concave mirror reflects light rays through its focal point, the teacher used the term “spread out,” which could lead students to incorrectly believe that concave mirrors scatter light into multiple beams upon reflection. Similarly, in Line 4, the teacher compared the behavior of a concave mirror to the behavior of a lens, stating that “this mirror is just like the lens is bending the light rays” (Line 4). This statement conflates reflection and refraction, as a concave mirror focuses light by reflecting it off its curved surface, while a lens focuses light by refracting it as it passes through the transparent material. Finally, in Line 6, the teacher suggested that placing a lens in front of a concave mirror would “counteract” the light, which is also a misconception. A lens and a concave mirror do not counteract each other; their combined optical behavior depends on the specific arrangement and focal properties of both elements.

In response to the teacher’s “mini-lecture”, the students incorporated the teacher's suggestion and proceeded to test the idea of placing a lens in front of the concave mirror. Ben enthusiastically said to Daniel, “Oohh, Daniel, we just figured it out” (8:22 - 8:27), signaling their excitement about implementing the teacher’s suggestion. Following this statement, the group spent four minutes setting up a new prototype with a lens in place as suggested by the teacher (PROTO) and engaged in several EPEs.

The group then started to test their design with the lens positioned in front of the concave mirror from 13:02 to 13:26. During this testing, they continued to struggle with predicting the way the light would reflect from the concave mirror. As they kept struggling, Ben expressed frustration, saying, “Should we just not do this double thing?” while picking up the lens (13:27–13:30). He then proposed an alternative design, suggesting, “And just let it come out like this?” as he removed the concave mirror from the design field to simplify it into a “single M” design (13:30–13:34). Despite this momentary shift in focus, the group continued to grapple with their original “double M” design, tweaking with the concave mirror’s angle to achieve the desired reflection. Instead of using a lens, they moved away from the teacher’s suggestion as it didn’t help them to understand and therefore solve the problem of the concave mirror. Subsequently, Cameron figured out the problem, and said, “We need to make something for it to lean against” (13:51-13:52), as he suggested to prop up the concave mirror using a lens.

The third interaction occurred on day 18 as the group was still tweaking the position of the concave mirror in their “double M” design. The teacher approached them to check on their progress (see Table 8).

Table 8

Example of Teacher Support During the Testing Phase on Day 18

Line	Time Stamp	Speaker	Dialogue [and gestures]	Discursive Moves Codes	Teacher's EPE Codes	Student's EPE Codes
1	17:08-17:12	Teacher	Gentlemen have you already tested?	PaceCheck,		
2	17:12-17:14	Teacher	Have you, did your intruder go in the building already?	Cue	CTXT, ADS-CC	
3	17:14-17:17	Ben	That's what we need [reaches for something in the supply box]			
4	17:17-17:18	Teacher	Whatcha been doing all this time?	PaceCheck		
5	17:18-17:19	Cameron	Well, trying to get this all set up [Ben puts the intruder at the start of the model].			
6	17:18-17:21	Ben	Trying to get this to go back [Ben puts the lens back].			MTRL-CON
7	17:21-17:25	Teacher	So, you've gotta set up per your drawing.	Dir		
8	17:25-17:34	Teacher	Okay, and if it's not working, and if it's not working on your thing, we need to answer those questions, and move on.	Dir	LFDF	
9	17:34-17:38	Teacher	And so, when we re-design…			
10	17:38	Ben	We can just change it			
11	17:38-17:43	Teacher	Because if we use our entire time, goofing around with that mirror, what did we learn for the testing?			
12	17:43-17:45	Teacher	That it doesn't work as well as you thought.		LFDF	
13	17:45-	Teacher	Right?		LFDF	
14	17:45-	Ben	Yeah,			
15	17:45-17:51	Teacher	And we need to change our design on that portion and move on.	Dir	LFDF	
16	17:51	Teacher	Okay.			

17	17:51	Ben	Okay.			
18	17:51-18:05	Teacher	So instead of wasting all of that time, with one component, one material, on there, an easier solution would be let's look at the questions that will help us analyze our data so that we can move on with this engineering design process. [Ben is slowly moving the intruder back and forth in the model.]	Dir	EBD	
19	18:05-18:10	Ben	So he runs through totally four here [Ben moves the intruder from the back to the front near the camera.]			ADS-CC
20	18:10-18:11	Teacher	Alright?			
21	18:11-18:15	Ben	He runs through four times [motions with the intruder].			ADS-CC
22	18:15-18-17	Teacher	Okay, another group needs this [refers to the laser], who has already tested and collected that data.			

The teacher began by asking whether the students had completed their testing and whether the intruder had been tested within their model (Lines 1–2). The students responded by quickly grabbing the intruder from the supply box (Line 3) and initiating a test to check if the intruder crossed at least three laser beams (Lines 18–21). During this brief test, the students engaged in the epistemic practice of *Assessing a Solution Based on Criteria and Constraints (ADS-CC)* to determine whether the intruder crossed the laser beams three times, as required by the design criteria. After moving the intruder through their laser security system, Ben concluded, “He runs through four times” (Line 21). However, the teacher did not listen to Ben’s conclusion; instead, he focused on moving the students on to complete their packets.

While Ben complied with the suggestion to check how many times the robber crossed the laser beam, he also tried again to express their problem with understanding how to reflect light from the concave mirror (line 6). However, the teacher was focused on redirecting the boys to begin answering questions in their worksheet. Following this conversation, the students shifted focus to completing their packets until the end of Day 18.

As they were completing their packets, Cameron asked a question to the group, “Guys, what were our results?” (28:59). Daniel and Ben answered Cameron’s question, “Our design did not work” (29:00–29:03) and “That our design failed and that we need to redesign” (29:04–29:06), respectively. Following this conversation, Daniel asked a reflection question to the group, “Guys, what have we learned? (30:02 – 30:04). Cameron answered directly, “That everything would have worked if it wasn't for that one mirror!” This final conversation on Day 18 indicated that the teacher has not addressed the students’ concern about concave mirrors yet, and missed an opportunity to engage with the students’ concern and understand their design.

Teacher Interaction on Day 19

The fourth and final interaction occurred on Day 19, as the group decided to retest their “double M” design. The teacher’s interaction was limited to a brief, generic check-in (see Table 9). This interaction, which consisted of simple inquiries about their progress and whether they had any questions (Lines 1–3), did not trigger the students to engage with any EPEs. However, despite the lack of substantive teacher support, the group successfully made their “double M” design work. After conducting the test, Alex concluded, “It works, okay” (15:27), and Ben echoed his assessment, stating, “It works, it’s just that the mirror has a problem. It angles down. We know it works” (15:29–15:37).

Table 9
Example of Teacher Support During the Testing Phase on Day 19

Line	Time Stamp	Speaker	Dialogue [and gestures]	Discursive Moves Codes	Teacher’s EPE Codes
1	6:38 - 6:40	Teacher	How’s it coming over here, fellows?	GenCheck	
2	6:40	Daniel	Good.		
3	6:41	Teacher	Questions?	GenCheck	
4	6:43	Daniel	Well…		
5	6:44	Ben	This is what happens. [Teacher walks over to another group]		

Discussion

In this study, we identified several examples of teacher support across the three engineering design phases–brainstorming, planning, and testing. These findings underscore the nuanced role of the teacher in facilitating students’ engagement with EPEs.

During the brainstorming phase, the teacher’s support was instrumental in promoting engagement with key EPEs, such as evaluating multiple solutions, assessing a design based on criteria and constraints, and considering multiple design solutions. This is consistent with the existing literature, which emphasizes the importance of early-phase teacher support to help students engage deeply with the problem-solving process (Kolodner et al., 2003; Crismond & Adams, 2012). In particular, teacher moves such as encouraging students to generate multiple ideas and solutions helped broaden students’ perspectives and innovation on the problem. This interaction laid the foundation for deeper engagement with EPEs, as students began to critically develop, evaluate, and justify their design choices. This extends the prior research that showed such discursive moves are pivotal in nurturing iterative problem-solving and innovation (Mahalik et al., 2008).

In the planning phase, the teacher's support was focused on providing explicit instruction on measuring angles and drawing the blueprint. This move, while helpful in clarifying procedural knowledge, did not afford students with opportunities to think more deeply about their plans in this phase. Research suggests that while explicit instruction can be effective in addressing gaps in students' technical understanding, it should be complemented with opportunities for students to engage in independent exploration and critical thinking (van den Akker et al., 2020).

The testing phase included more frequent teacher interaction, with interventions aimed at facilitating students to optimize their design, encouraging testing based on criteria and constraints, and maintaining pacing to meet time constraints. However, these interactions often lacked the depth necessary to guide students toward meaningful revisions of their designs and understanding of reflection on a concave mirror. Research has shown that while teacher questioning can help students engage with design criteria, its effectiveness depends on how well it prompts students to reflect and articulate their reasoning (Kolodner et al., 2003; Chin et al., 2006). Unfortunately, in this study, the teacher's discourse moves did not elicit student reasoning and engage students more deeply with EPEs. For example, during discussions about alternative artifact placements, the teacher posed several questions to check students' understanding of the design criteria. Although the students provided correct responses, the teacher did not prompt them to elaborate on their reasoning, missing an opportunity to guide them in articulating why certain placements would fail to meet the criteria and ultimately reveal their need to understand how light reflects from a concave mirror. Such missed opportunities highlight the need for scaffolding strategies that encourage students to connect their decisions to broader scientific and engineering principles (Mehalik et al., 2008; Crismond & Adams, 2012).

Moreover, the teacher's guidance during critical moments often redirected the conversation away from the students' expressed challenges. For example, when students struggled with the properties of the concave mirror, the teacher shifted focus to the use of a lens without addressing the underlying difficulties. This misalignment between teacher moves and student needs limited the potential for meaningful design refinements and iterative learning. These findings echo earlier studies emphasizing the importance of responsive teaching strategies that adapt to students' needs and scaffold their engagement with EPEs (Crismond & Adams, 2012; Rose et al., 2020). Responsive teacher moves should not only respond to the students' needs, but also prompt students' reasoning and scaffold their understanding (Ruthven et al., 2017).

The introduction of misconceptions during teacher interactions further highlights the importance of teacher content knowledge in supporting student engagement with EPEs. Misconceptions about fundamental concepts, such as the behavior of light with concave mirrors and lenses, may inadvertently reinforce incorrect understandings, limiting students' ability to optimize their designs. This finding aligns with existing literature, which emphasizes the role of accurate and clear communication in facilitating student learning during complex design tasks (Mehalik et al., 2008; Teo, 2016).

The study also highlights the moments where the teacher's discourse successfully facilitated students' engagement with specific EPEs and helped them move forward. Research suggests that effective cue strategies by teachers can encourage students to remain focused and actively engage with task-specific goals (Kolodner et al., 2003; Mehalik et al., 2008). For instance, in this study, checking whether students had conducted testing prompted them to initiate testing immediately and engage in assessing their design based on criteria and constraints. Such interactions underscore the importance of teacher interventions in maintaining momentum and ensuring that students address critical design requirements (Crismond & Adams, 2012).

Limitations

This study is based on a single case study of one teacher who participated in extensive professional development prior to implementing the integrated STEM unit. While this focused approach provides in-depth insights into teacher-student interactions and the resulting engagement with EPEs, it also limits the generalizability of the findings. Further research could expand this study by involving a broader range of teachers across pedagogical contexts, such as other middle school settings, informal learning environments, or classrooms led by educators without similar professional development experiences. This could reveal variations in discursive moves and potentially uncover additional teacher strategies beyond those identified within the frameworks used in this study. Additionally, further research could also extend this study by involving more diverse compositions of student groups. By involving a more diverse and broad number of students, further study could unveil whether particular students' engagement with EPEs was triggered by teacher moves, the nature of the task itself, students' intrinsic motivation, or students' prior knowledge and experiences.

Implications

The study addresses a critical gap in the literature regarding teacher support for students' engagement with EPEs. This area remains underexplored in STEM education research. By examining the nuanced interplay between teacher moves and students' participation in EPEs, this research contributes to the evolving discourse on effective pedagogical practices in STEM education. These findings underscore the importance of equipping teachers with targeted strategies to support student engagement in complex problem-solving, reasoning, and design-thinking processes.

Moreover, this study holds implications for teacher preparation and professional learning. Specifically, it highlights areas that warrant focused attention, such as strategies for fostering student autonomy, encouraging critical reasoning, and effectively guiding iterative design processes. Additionally, teacher professional learning opportunities should emphasize strategies for balancing direct guidance with opportunities for student-led inquiry to optimize engagement with EPEs. By addressing these areas, teacher preparation and professional learning programs can better support educators in developing the skills and strategies to facilitate meaningful student engagement with EPEs, ultimately enhancing the quality of STEM learning experiences and outcomes.

Conclusions

This study offers insights into how teacher-student interactions during small-group engineering design activities influence students' engagement with EPEs within an integrated STEM unit. The teacher employed various discursive strategies, including direct guidance, cues for reasoning, factual knowledge elicitation, and the provision of scientific canonical knowledge. These strategies supported students' engagement with a range of EPEs.

However, the findings also revealed that much of the teacher support provided was limited, with missed opportunities where teacher interactions lacked necessary follow-through to guide students toward deeper reasoning and independent problem-solving. In particular, these gaps were evident in moments when students needed support to understand the reflection of light from the concave mirror, which would have allowed them to optimize their "double M" design. Despite these limitations, the students remained on-task and successfully completed their engineering challenge, albeit without the inclusion of refraction in their design. The teacher's limited interactions—only six group-level interactions with this group—relate to the need to allocate time across multiple groups. This highlights the challenge of balancing attention and support in collaborative classroom settings.

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