Middle School Preservice Teachers' Talk Moves to Help a Team Consider how to Improve (Fundamental)

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Abstract

Engaging in productive diagnostic troubleshooting is critical to the engineering design process and a key aspect of informed designers' work. However, it can be challenging for beginning designers like elementary students to engage in productive diagnostic troubleshooting. Support from teachers can help students move from prototype testing towards informed improvement in future designs. However, there is limited research examining the nature of the talk moves that teachers use to support elementary students to engage in diagnostic troubleshooting. This qualitative study uses conversational analysis to investigate the types of talk moves that elementary preservice teachers use when facilitating a small group discussion to engage three student avatars in diagnostic troubleshooting within a simulated classroom environment. Study results illustrate that the preservice teachers were most likely to use various engineering support moves to support the students in addressing aspects of the design or design process by asking the students to describe or explain their first or second designs. While less frequent, preservice teachers also used talk moves (a) to encourage discussion among the students, most often by tracking student ideas, and (b) that may hinder the team's engagement in—and ownership of—the process of diagnostic troubleshooting, most often by evaluating students' ideas. Considerations and ideas about supporting preservice teachers in learning how to use talk moves to productively engage their students in productive diagnostic troubleshooting are discussed.

Introduction

After testing their prototypes, informed designers engage in diagnostic troubleshooting to determine their prototype's problems or weaknesses and figure out ways to improve their design in subsequent prototypes [1]. An essential part of engineering design, diagnostic troubleshooting process involves four steps: (1) observing the behavior of the prototype, including its performance during testing; (2) identifying ways the prototype failed or did not meet criteria, (3) explaining why failure occurred or why improvement is needed, and (4) remedying or improving for the next design/prototype [2]. Scholars have argued that design failures and the need to improve fuels student learning—perhaps even more so than when designs perform well [3, 4].

It can be challenging for beginning designers like elementary students to engage in productive diagnostic troubleshooting. For example, students may not notice where failure occurred, may struggle to explain the reasons for design failures as they relate to design features, and may be uncertain about how to improve or consider changes that may not be directly related to weaknesses in the design [3-10]. As reported in this literature, children can and do engage in diagnostic troubleshooting in productive ways, e.g., identifying strengths and weaknesses of their designs; drawing upon background information (e.g., relevant science, constraints, and criteria); and making well-reasoned improvements to their designs.

Teachers can play important roles in supporting students' engagement in diagnostic troubleshooting. Crismond and Adams recommended that teachers support students by having them (a) follow the four aforementioned steps; (b) engage in learning activities to help them learn how technologies work; and (c) engage in stations activities where students practice troubleshooting devices, each of which "possesses a noticeable flaw" (p. 768) [1]. These authors also recommend that teachers model troubleshooting behaviors and pose comments and questions to "help shift a students' analytical perspective and way of looking" to encourage diagnostic troubleshooting (p. 769).

Others have suggested that teachers intervene in certain ways—while not intervening in others—as students engage in diagnostic troubleshooting. Supportive post-testing interventions include offering encouragement; offering reminders to work well as a team and to learn from other teams; and suggesting that students reference background information (e.g., about science, constraints or criteria) [6, 11, 12]. Silvestri and colleagues suggested that teachers take on positions as observers, questioners, and those who elicit ideas [10]. As observers, teachers may decide to hold back, letting students engage in diagnostic troubleshooting and resisting the temptation to guide a team that does not need guidance. Contrastingly, teachers may offer too much direction or evaluation, stifling children's sensemaking and agency as designers [6, 8-10].

Facilitating discussions with teams is one approach used by teachers to support students as they engineer. However, the field needs a better understanding of how such facilitation occurs and how to support teachers, including preservice teachers (PSTs), in learning how to facilitate such discussions. In their 2022 literature review about design failures as learning experiences, Jackson and colleagues asserted that the engineering education community needs more research that closely analyzes interactions among the students and with the teacher [4]. To address this gap, we examined how PSTs facilitated a simulated small group discussion to engage a team of three middle school avatars in diagnostic troubleshooting.

Conceptual Framework

This study builds upon social constructivism [13, 14]; discussion, conversational analysis, and talk moves [15, 16]; and the practice of digital simulations to study how teachers facilitate discussions [17-19]. We address each of these in turn in this section.

Social Constructivism

To begin, we draw from social constructivism, which suggests that learning is a social process involving the co-construction of ideas as people interact with one another [13]. These interactions are not only between a teacher (or other adult) and students, but among the students [14]. A key idea in social constructivism is the Zone of Proximal Development (ZPD), which helps define an intermediate space between what a learner could do without assistance from another individual and what a learner could not do even with assistance. The intermediate space (ZPD) is what a learner has the potential to do with assistance. Ideally, teachers provide just enough and not too much assistance for students as they learn within their ZPD.

Discussion, Conversational Analysis, and Talk Moves

One way that teachers can support student learning through social interactions is by encouraging discussion (a.k.a. talk) (a) between the teacher and student and (b) amongst students. The study of talk and discussion is complex—and beyond the scope of this paper to thoroughly address. However, two concepts are especially important with respect to talk and discussion: conversational analysis [15, 16] and talk moves [20, 21].

Researchers can study discussions by observing them. Sachs focused on the systematic analysis of natural discussions between people, examining turn taking, speaker roles, the flow of discussions, and other topics, labeling this as conversational analysis [16]. Describing discussion as orderly and social in his chapter on conversational analysis, Horton offered:

> Despite all appearances to the contrary, even the most casual of conversations is assumed to be organized along principles that not only can be identified by the analyst through careful observation, but which are also used by the conversational participants themselves as a basis for understanding what is being accomplished through the interaction. (p. 27) [15]

Thus, conversational interactions—even natural, meandering talk in everyday discussions—is ripe for study related to the patterns therein.

In the context of teachers facilitating discussions with students, "talk moves," represent the questions and prompts that teachers use to encourage student talk with the teacher and other students during a discussion [20]. Talk moves aim to move away from traditional IRE patterns, i.e., when the teacher *Initiates* by posing a question, the student *Responds*, then the teacher *Evaluates* the student response. These patterns are common in classrooms but are problematic in limiting student talk and learning [22, 23]. Rather, talk moves aim to facilitate more interactive discussions that focus on helping students construct ideas with one another, engaging students in "productive talk" [20, 24]. Lists of talk moves are available in the literature, however, there is no singular list of talk moves that is robust for every type of educational discussion. An example of a seminal list of generic talk moves for use in science education is by Michaels and O'Connor [20]. It includes talk moves such as *say more* (e.g., "Say more about that, please"); *asking for evidence and reasoning* (e.g., How do you know?); or *agree or disagree and why* (e.g., What do you think about what Ava said?). Note that here and elsewhere in the paper we italicize the names of different talk moves.

Using Teaching Simulations to Study Discussion

Sachs [16] developed conversational analysis to investigate all types of naturally occurring conversations, from the mundane to the formal. We and others have used this kind of analysis to investigate simulated discussions between a teacher and student avatars; for example, see [25-29]. Specifically, we use the Mursion® simulated classroom environment. Mursion® is a platform that allows users (e.g., PSTs) to facilitate a discussion with up to five student avatars. The user connects to Mursion® through Zoom. The student avatars appear on the user's Zoom screen and can respond to the user and each other in real time.

The avatars are operated by a human-in-the-loop called an interactor or simulation specialist (hereafter, sim) [30]. Sims must receive Mursion® training to learn to use computer hardware and Mursion® software to act as any of the student avatars, with each avatar having a unique background, disposition, and voice. The sim virtually hops in and out of each student avatar during the conversation, e.g., responding to a user's question as avatar Ava and responding to avatar Ava's response as avatar Ethan. The user only sees and interacts with the avatars; the sim themselves and their background work is out of view. In addition to basic Mursion® training, sims also receive training related to particular discussion topics and constraints around those topics, which are referred to as scenarios or tasks. For example, in the discussion task used in our study, a PST aims to help a team move forward in their diagnostic troubleshooting process. The sim must know about the team's design, each team member's initial ideas about the design and how it might be improved, and under what circumstances team members might be willing to change their thinking. Sims aim to be consistent across PSTs facilitating the same discussion.

In teacher education, simulations are used to study how teachers, including PSTs, facilitate discussions [25-29]. The simulated environment allows for comparison across PSTs facilitating the same discussion with the same students, enabling researchers to analyze discussion transcripts to look for patterns, including talk moves or other discussion features, across PSTs. Teacher educators using simulated environments as practice tools can analyze discussion transcripts to provide feedback to help PSTs improve in their use of talk moves and other discussion strategies.

Literature Review

Two areas of research are relevant to this study: (1) talk moves used by teachers, including PSTs, in engineering education; and (2) the use of discussion-based simulated classroom environments in engineering education research.

Talk Moves in Engineering Education

There is relatively little focus on teacher talk moves in engineering education; however, two studies provide particularly rich insight [31, 32]. One of these is a 2023 study by Miel and colleagues that examined the talk moves used by novice engineering outreach educators as they interacted with upper elementary (ages 9 and 10) design teams [32]. Acknowledging the richer history of talk moves documented in the literature for science, mathematics, and literacy education, they aimed to create a "baseline of existing talk moves" for engineering through their observations of the engineering educators. They looked for three categories of talk moves, i.e. ambitious, conservative, and inclusive [33, 34]. Drawing from literature on "ambitious teaching" (for example, [35-37]), Miel and colleagues argued that ambitious talk moves are those that support students' engineering design thinking and sensemaking. In contrast, conservative talk moves either deliver information or elicit a particular answer. Inclusive talk moves aim to include all student voices and ideas in the discussion.

Study findings illustrated that the novice engineering outreach educators used talk moves across all three categories. Most moves were conservative; fewer were ambitious and still fewer inclusive. Conservative talk moves included *display question*, where educators asked for simple facts, typically with one right answer; *evaluate correctness*, where the educator evaluated the correctness of students' ideas, designs, or processes; *minilecture or suggestion*, where they delivered content "in the form of a design-related suggestion, content about the activity, or disciplinary norms" (p. 343), and *process management*, where they reminded students about materials, time, or instructions. Process management was the most observed talk move across all three categories. Talk moves in the ambitious category included *design check-ins*, where educators asked teams about their design progress; *probing question and follow-up probe*, where they posed initial and follow-up open-ended questions about teams' designs; and *press for explanation*, where they asked teams to share reasoning about their designs. In the *inclusive* talk move category, the researchers observed talk moves such as *distribute participation*, when they asked others to respond or build on others' ideas; *acknowledge contribution*, where they encouraged students and their contributions "without indicating correctness" (p. 343); and *repeat*, where they restated a student's contribution to acknowledge it or seek clarity about it.

Aranda and colleagues explored the moves used by two secondary science teachers as they taught a biology unit with an integrated design challenge related to genetically modified organisms [31]. Although they did not use the same conservative, ambitious, and inclusive categories as did Miel and colleagues [32], their findings were—in essence—similar. The teachers used conservative talk moves much more frequently than moves that could be described as ambitious or inclusive. These studies begin to address a key gap in the research literature to understand the nature of the talk moves that teachers use within engineering instruction. They offer initial insights into both the type and frequency of the moves used within specific engineering learning contexts and grade levels. Additional research is needed to explore to what extent such talk moves are observed across contexts and the nature of talk moves within key aspects of the engineering design process. This study builds upon these studies by using a similar process of conversational analysis to examine both the type and frequency of talk moves that might support and hinder students' engagement in a critical part of the engineering design process: diagnostic troubleshooting.

The Use of Digital Simulated Classroom Environments in Engineering Education

Although digital technical simulations (i.e., those that model some technical phenomena like fluid flow simulations) have been examined frequently in the engineering education literature, digital teaching simulations, where teachers can engage in specific teaching practices using simulated classrooms like Mursion®, have not. This small body of literature includes work by the authors. One study investigated the talk moves that PSTs used when they facilitated a discussion with one middle school avatar experiencing idea fixation [38]. PSTs used talk moves that supported the student's engagement in brainstorming (e.g., asking about their favored idea, encouraging student thinking about another idea, sharing the importance of having multiple ideas) or hindered it (e.g., if the PST evaluated the students' idea(s) or suggested ideas). Another study investigated how in-service teachers facilitated discussions with a group of five upper elementary school avatars divided into two teams and one singlet. The goal of the discussion was for the avatars to share and compare their designs and test results and offer feedback to one another about how to improve [39, 40]. A final set of studies is set in the context of a large introductory undergraduate engineering course. These studies aim to explore how undergraduate teaching assistants for the course facilitate discussions with team members on a simulated team that is experiencing interpersonal conflict [41-43].

Clearly, there is room for more engineering education researchers to use digital teaching simulations to investigate talk moves and discussion strategies [44]. Through the present study, we hope to contribute to the knowledge base on the talk moves that PSTs use—and might consider using or try to refrain from using—as they engage students in diagnostic troubleshooting. We also hope to demonstrate how these simulations can be used to investigate a wider range of discussions that support student engagement and sensemaking throughout the design process.

Research Questions

The research questions that guide this study are: *What talk moves do PSTs use as they facilitate a discussion with a team unsure about how to improve? How might PSTs' talk moves support or hinder the team's engagement in diagnostic troubleshooting?* (Note: We use "talk moves" here to mean the questions and other prompts the PSTs use during the discussion, whether they support or hinder students' engagement in diagnostic troubleshooting and discussion.)

The context for these research questions is a situation in which a team of three student avatars in the Mursion® middle school classroom is struggling to determine how to improve their prototype after testing their first design. Each participating PST intervenes to help the team engage in diagnostic troubleshooting by facilitating a team discussion. Prior to this intervention, PSTs have not learned about talk moves or strategies to support diagnostic troubleshooting during discussions. Thus, we aim to understand the range of moves that PSTs use as a starting point for their learning process as teachers of engineering. This understanding will allow the field to identify the assets that PSTs bring with them to support productive diagnostic troubleshooting, as well as ways they might improve in their subsequent instructional practice.

Methods

In this qualitative study, we answer the research questions using conversational analysis to investigate and describe the PST talk moves within discussion transcripts [15]. We begin this section by describing the study participants and the course in which they are enrolled. We then summarize two simulated engineering teaching experiences in the course, which include the discussion of focus for this paper (the second experience) and the first experience that precedes it. We then describe the data we collected and how we analyzed those data.

Participants and Course Context

Study participants were 19 PSTs who (a) were enrolled in an engineering teaching methods course in fall 2021, 2022, or 2023 at Towson University, a large public university in the mid-Atlantic US, and (b) consented to participate in research according to our approved Institutional Review Board protocol. The 19 participants were in one of three sections of the course offered over three consecutive years (90% participation rate). The participants were in their second or third years at the university and had no or minimal field experiences or interactions with the Mursion® simulated environment. We did not gather demographic data from the participants. The students in the course reflect the demographic diversity at the university with respect to race and ethnicity: 40% White, 33% Black/African American, 11% Hispanic or Latine, 6% Asian, 5% two or more races, 1% international, and 5% other.

Offered once per year each fall, the two-credit methods course is required for all PSTs who declared science as one of their two subject area specialties at the university. The course aims to prepare PSTs to teach engineering, especially science-integrated engineering design that helps to meet the Next Generation Science Standards [45]. Since the inception of the course in 2011—except for fall 2020 and fall 2021 which were affected by the COVID pandemic—the course has included a field placement in the final third of the course. The field placement involves PSTs co-teaching a science-integrated engineering design challenge to middle school students, applying what they learned in the first two thirds of the semester.

Simulated Engineering Teaching Experiences in the Course

Beginning fall 2021, we developed and implemented a suite of simulated engineering teaching experiences to enable PSTs to try facilitating challenging engineering discussions with avatars in lieu of (for fall 2021) or before (for fall 2022 and 2023) teaching real students in the field placement. These experiences used the Mursion® middle school simulated classroom (first two experiences) and the elementary school simulated classroom (third experience) with simulation scenarios designed by the authors [39, 46]. See Figure 1 for the middle school simulated classroom. The first experience only used avatar Savannah. The second experience for the current study, used only Ava, Jasmine, Ethan.

Figure 1. Mursion® Middle School Student Avatars (used with permission)

Towson University has a Mursion® license, Dr. Lottero-Perdue (first author and course instructor) is trained as a Mursion® sim to act as and operate the student avatar(s) in the middle school simulated environment. All PSTs in the course were required to facilitate the simulated discussions and did so outside of regular class time at a time that worked for both the PST and the course instructor, connecting to the simulation through Zoom. The PSTs were not made aware that their course instructor was the sim until all simulated engineering teaching experiences were complete for the semester. After PSTs completed each simulated teaching experience, PSTs analyzed their discussion videos and transcripts, and the instructor facilitated a whole-class discussion about what went well and could be improved in future discussions with real or avatar students.

The first of the simulated engineering teaching experiences was an approximately 7-minute one-on-one discussion that each PST had with a single student avatar, Savannah. We provided scenario materials to the PSTs to help them prepare for the discussion. The scenario materials explained that Savannah was experiencing idea fixation during brainstorming within a wind turbine blade design challenge; she had included just one idea on the brainstorming page of her engineering notebook. PSTs in all three sections of the course were familiar with the wind turbine blade design challenge because they had done the challenge themselves as students. We also created scenario materials for the sim, which included a list of possible questions PSTs might ask and sample ways for the sim to respond. These sim guidelines help the sim balance the need to be responsive to PST questions while being consistent across multiple PSTs facilitating the same discussion. We have reported on this scenario and research related to it [38, 46].

This first simulated experience was helpful in acclimating PSTs to the Mursion® environment prior to facilitating the second simulated engineering teaching experience, the one of focus for this paper. Participants engaged in this second experience two or three weeks after engaging in the first one. Like the first experience, the scenario was set in the context of the wind turbine blade design challenge. However, the second experience involved talking to the team of three student avatars (hereafter, students)—Ava, Jasmine, and Ethan, a.k.a. Team AJEs Ago—who were struggling to engage in diagnostic troubleshooting after testing their first wind turbine blade design (Design 1 or D1). The three-page scenario that we provided to the PSTs to help them prepare is shown in full in the Appendix and included:

- A description of where students were in the design process
- A table of scientific evidence and claims related to multiple wind turbine variables based on the students' previous data collection (e.g., number of blades)
- A description and image of the team's D1 blade system on the model wind turbine (see Figure 2 for image)
- A description of what the teacher (i.e., the PST facilitating the discussion) asked students to do after testing, i.e., engage in diagnostic troubleshooting by reviewing test results and consider how they might improve prior to creating Design 2 (D2)
- What the teacher noticed when checking on the team, i.e., that they were not interacting with one another and didn't seem to be writing in their notebooks
- The two goals for the discussion the PST is to facilitate with the team, i.e.:
    - To elicit from Ava, Jasmine, and Ethan the results of their D1 testing, their ideas that went into D1, and their current ideas about how they might improve their design (to plan for D2)
    - To support this team to engage in diagnostic troubleshooting and determine productive ways to improve their design
- A paragraph of information about each of the students from team AJEs Ago, accompanied by an image of each student

Figure 2. Image of Team AJEs Ago Design 1 Wind Turbine Blade System

The only preparation that the PSTs received prior to facilitating the discussion with team AJEs Ago was: (1) facilitating and then debriefing after the first simulated engineering teaching experience with Savannah about idea fixation, (2) engaging in their own diagnostic troubleshooting during the wind turbine design challenge earlier in the course, and (3) receiving and reviewing the scenario materials described above and in the Appendix about one week before facilitating the discussion.

Data Collection

We gathered Zoom videos and auto-generated transcripts from all 19 participants. We used the videos to correct the transcripts and replaced participant names in the transcripts with identification numbers (e.g., PST 05). For this paper, we used pseudonyms to replace identification numbers for two of the participants: PST 05 (Finley) and PST 11 (Venice). We chose these two participants because together their transcripts help to contextualize the codes we applied across all participants.

The focus of our analysis was on the "turns" by PSTs within their transcripts. A turn is an utterance from a speaker in a discussion. For example, Table 1 is an excerpt from a discussion transcript. In this excerpt, there are five turns from the PST, two turns from Ethan, and two turns from Jasmine. In this study, we coded the PST turns, using the student turns to help interpret the PST turns. The number of PST turns per transcript ranged from 23 to 78 turns (median = 33); there were 629 total turns across the 19 PSTs.

Table 1. Example Transcript Excerpt

Speaker	Turn
PST:	You don't think you could improve at all?
Ethan:	Well, I don't know. I mean 710 millivolts was pretty good. So, I guess it's possible, but I'm, I'm pretty satisfied.
PST:	Maybe we should try to improve our results. You never know, you could get even better number.
Ethan:	Ooh. An even better number. Huh?
PST:	Mm-hmm.
Jasmine	Yeah
PST:	Have you guys talked about it at all? I'm sorry, Jasmine, go ahead.
Jasmine:	No, I, I, I'm glad you're - you're telling him to, to think about another one. We haven't really talked about it because, well … he didn't really talk about it before. And I had an idea to change blades and I think Ava's idea's a little different …
PST:	What were you thinking for your idea, Ava? Why don't you guys discuss it a little?

Data Analysis

The two authors began conversational analysis [15] of the discussion transcripts using an existing codebook from our prior work [46]. In that codebook, codes were organized into three main talk move categories: (1) Engineering Support moves, which addressed aspects of the design or the design process; (2) Discussion Support moves, which encouraged student talk; and (3) Hindering Moves, which had the potential to hinder the team's engagement or ownership of the process of diagnostic troubleshooting (Tables 2, 3, and 4). For the present work, we refined code descriptions in the codebook and added one Engineering Support move code for when PSTs specifically encouraged the team to document their D2 ideas.

Table 2. Talk Move Codes in the Engineering Support Moves Category

Talk Move Codes	Code Description – The PST:
Design 1 (D1)	Asks the team to share details or provide reasoning about D1
Design 2 (D2)	Asks the team about what to include for D2 in general or compared to D1
Science	References the scientific data or asks the team to consider, share, restate, or reference evidence/data or claims from the scientific investigations
Iteration	Suggests that it is important to iterate/improve in the design process or that D1 can be improved with another iteration
Progress	Checks in with where the team is, what is going on, or asks the team to explain their progress or lack thereof in coming up with D2
Documentation	Encourages students to sketch or document their D2 ideas

Table 3. Talk Move Codes in the Discussion Support Moves Category

Talk Move Codes	Code Description – The PST:
Teamwork	Encourages students to work together, listen to one another, or be a team; or suggests the importance of teamwork/collaboration
Tracking Student Ideas	Identifies and references specific ideas from team members during the discussion; could occur immediately after a student shares or later
Building on Student Ideas	Encourages students to consider specific design ideas posed by other students
Prompting Student-to-student Talk	Explicitly encourages students to talk to one another
Allowing Substantive Talk	Allows students to talk with one another without interrupting (counted if there are three or more student turns of substantive talk in a row; continuers/ interjections like “mm hmm” by the PST are not counted as interruptions)

Table 4. Talk Move Codes in the Hindering Moves Category

Talk Move Codes	Code Description – The PST:
Evaluate Design 1 (D1)	Evaluates or shares strengths/weaknesses of D1 or aspects of D1; includes evaluating the output (e.g., that 710 mV is good)
Evaluate Design 2 (D2)	Evaluates or shares strengths/weaknesses of D2 or aspects of D2
Offer Variables	Suggests variables (e.g., number of blades) the team should focus on or change for D2 without the team discussing the variable first for D2
Offer Ideas	Suggests design ideas for D2 (e.g., to use 3 blades or a certain shape)

Our coding process involved three phases. In the first phase, we collaboratively coded two of the 19 transcripts chosen at random. Next, we double coded four additional transcripts, again chosen at random. This step involved each co-author independently coding the transcripts and then the co-authors meeting to reconcile differences. Prior to reconciliation, intercoder agreement ranged from 91% to 96% across 13 of the 15 codes. Two codes, *D2* in the Engineering Support Moves category and *tracking student ideas* in the Discussion Moves category, had lower rates, i.e., 76% and 83% respectively. Across all 15 codes, the ICC was 0.792 for average measures. Prior to the third phase, we revisited those codes, refining code descriptions and determining how to proceed more consistently. In the third phase, the first author coded the remaining 13 transcripts independently, flagging any coding decisions where the she was uncertain. The co-authors met to discuss those areas of concern and come to consensus on final coding decisions. We applied between 0 and 5 talk move codes to each PST turn (median = 1 code per turn); we applied at least one talk move code to 85% of 663 PST turns across the 19 transcripts; 15% of PST turns received no code.

We calculated code frequencies for each talk move category and code across all PSTs and per PST. We also calculated minimum, maximum, and median percentages for each category across

PSTs. We did not code student turns, except as we tracked for instances of the PST allowing student-to-student talk, a discussion support move. We used student turns to provide context for our coding decisions related to PST turns.

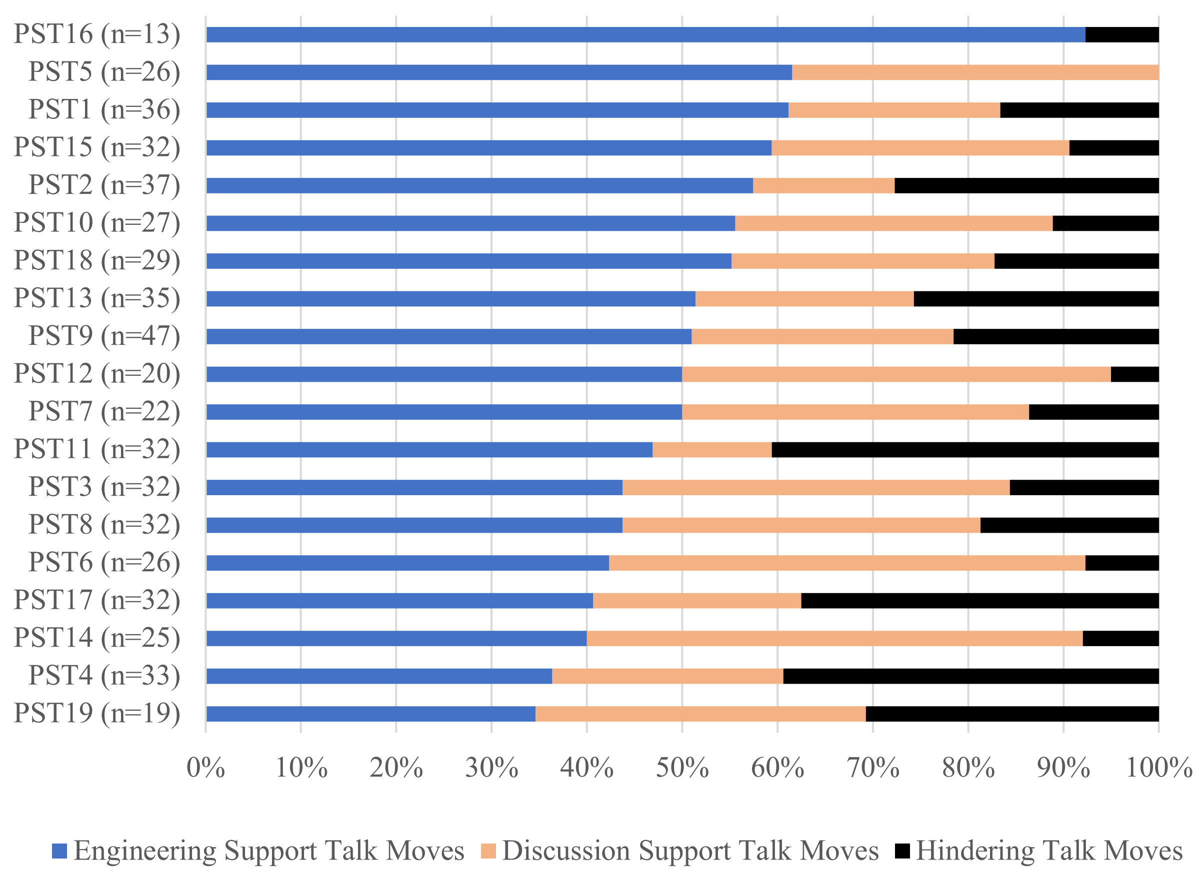
Findings

In this section, we first describe the talk move categories and codes used across all 19 PSTs. Next, we share discussion excerpts from two PSTs, Finley and Venice (pseudonyms), to provide examples of talk moves in the context of their discussions.

Talk Moves Used Across the PSTs

Figure 3 shows the percentage of Engineering Support, Discussion Support, and Hindering talk moves within each PST's transcript. We calculated percentages based on the total number of talk moves within each transcript as indicated in the figure (e.g., 13 talk moves for PST16). See Table 5 for the minimum, maximum, and median percentages across categories and PSTs/transcripts.

Figure 3. Distribution of Talk Moves across Three Categories for Each PST



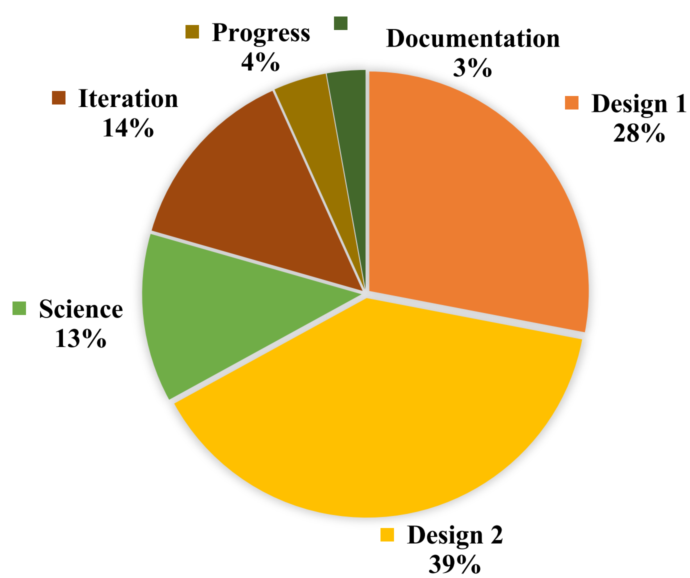
Note. Values of "n" shown in the y-axis are the total number of talk moves coded within each transcript (e.g., 13 talk moves for PST 16). This is different from the number of turns in the transcript as there may be more than one talk move code assigned per turn.

Table 5. Percentages of Talk Move Categories Per PST/Transcript

PST Move Category	Minimum Percentage of Coded Turns Per PST/Transcript	Maximum Percentage of Coded Turns Per PST/Transcript	Median Percentage of Coded Turns Per PST/Transcript
Engineering Support	35%	92%	50%
Discussion Support	0%	52%	31%
Hindering	0%	41%	17%

Across the 19 transcripts, we applied 564 talk move codes, including 284 (50%) in the Engineering Support category; 168 (30%) in the Discussion Support category, and 113 (20%) in the Hindering category. Figure 4 shows the frequencies of talk moves within the Engineering Support category. Most of these talk moves inquired about D1 or D2 (67% of 284 Engineering Support talk moves). Together, these *D1* and *D2* talk moves codes represent the most frequent talk moves across the three categories.

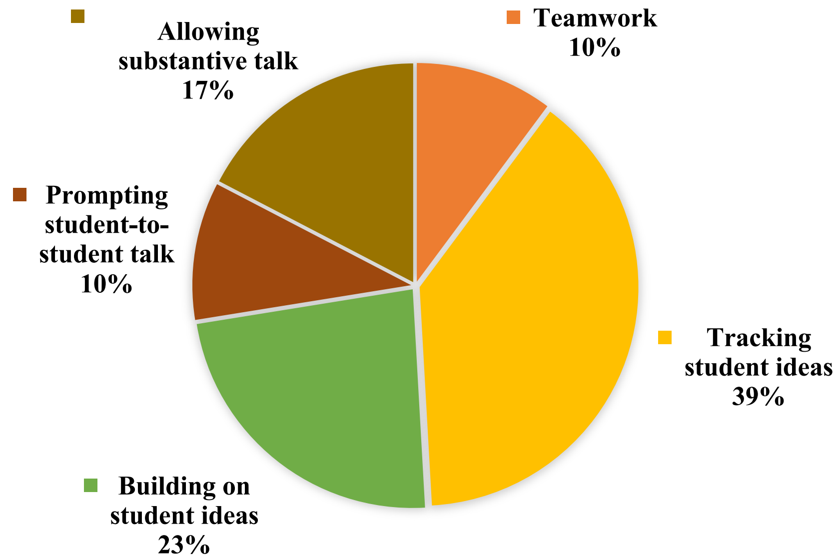
Figure 4. Engineering Support Moves across 19 PST Participants (n=284)



Note. Percentages add to 101% due to rounding.

See Figure 5 for the frequencies of Discussion Support talk moves across the PSTs. Most often, this involved tracking student ideas—picking up what students shared to move the discussion along (39% of 168 discussion support moves).

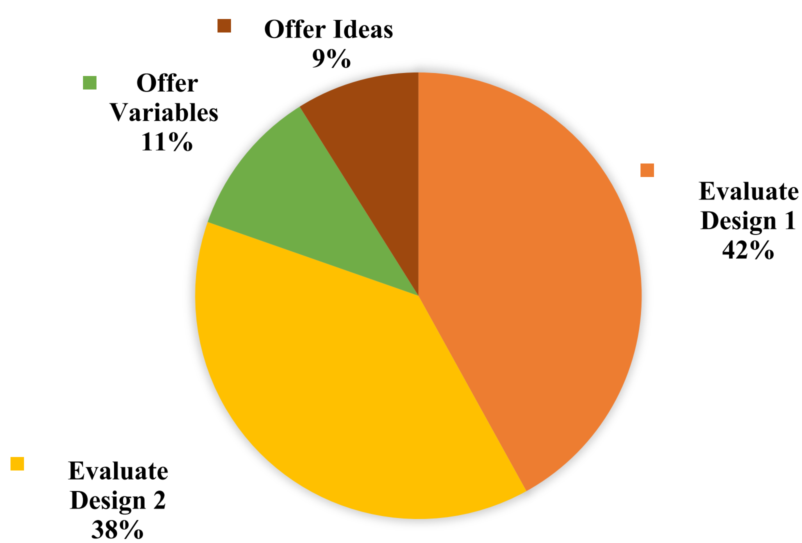
Figure 5. Discussion Support Moves across 19 PST Participants (n=168)



Note. Percentages add to 99% due to rounding.

Of the 113 talk moves in the Hindering category, the majority (80%) were instances in which the PSTs evaluated—mostly through praise—the team's D1 or D2 ideas (Figure 6). As mentioned earlier, the trouble with this, even if well intended, is that the authority of the PST may interfere with the students' evaluations of their own designs. The remaining 20% of hindering talk moves were either when the PST offered either suggestions about which variables to consider changing for D2 (e.g., asking about the hub-to-blade distance when this variable was not mentioned by the students) or specific design ideas (e.g., suggesting a specific number of blades to use for D2).

Figure 6. Hindering Moves across 19 PST Participants (n=113)



Examples: PST Finley and PST Venice

In this section, we share discussion segments from two PSTs, PST Finley and PST Venice. For reference in Figure 3, their identification numbers were PST 5 and PST 11, respectively. We chose PST Finley and PST Venice because they enable us to provide examples across all talk move categories and codes. Also, while both have somewhat higher-than-average instances of Engineering Support talk moves, they differ with respect to their use of Discussion Support and Hindering talk moves. PST Finley had more than twice as many Discussion Support talk moves as did PST Venice. PST Finley had no Hindering talk moves and PST Venice, along with one other PST, had the highest number of Hindering moves across the PSTs. See Table 6 for a summary of talk moves in PST Finley and PST Venice's transcripts.

Table 6. Talk Moves in PST Finley's and PST Venice's Transcripts

Talk Move Category (Abbreviation)	PST Finley	PST Venice
Engineering Support (ES)	**16 =** 1 *Design 1* + 11 *Design 2* + 1 *Science* + 1 *Iteration* + 1 *Progress* + 1 *Documentation*	**15 =** 6 *Design 1* + 6 *Design 2* + 1 *Science* + 1 *Iteration* + 1 *Documentation*
Discussion Support (DS)	**10 =** 3 *Building on Student Ideas* + 5 *Prompting Student-to-student Talk* + 2 *Allowing Substantive Talk*	**4 =** 1 *Teamwork* + 1 *Tracking Student Ideas* + 2 *Building on Student Ideas*
Hindering (H)	**0**	**13 =** 7 *Evaluate Design 1* + 3 *Evaluate Design 2* + 2 *Offering Variables* + 1 *Offering Ideas*

PST Finley

PST Finley opened the discussion with: "Why don't we talk to your teammates, and we can see what's going on with … your project." This was the first of five separate instances throughout the roughly 9-minute discussion where she prompted students to talk to one another (*DS Prompting Student-to-Student Talk*). Note that from this point forward, we will indicate codes using italics and will state the talk move category abbreviation (first column of Table 6) and code name. Next, PST Finley briefly inquired about the results of D1 testing, asking, "How did the test results go for D1, Jasmine?" (*ES D1*). PST Finley then shifted into asking about the team's D2 ideas (*ES D2*). During this inquiry, PST Finley learned that Jasmine wanted to add more blades; Ava had an improvement idea but did not share it because, in Ava's words, "Ethan wasn't really interested in talking about changing;" and Ethan was satisfied with D1 and did not see a reason to create a D2. The discussion excerpt in Table 7 begins with PST Finley's reaction to Ethan's satisfaction and shows how PST Finley encouraged Ava to share her improvement idea. We applied the talk move codes *ES D2*, *ES Iteration*, *ES Progress*, and *DS Prompting Student-to-student Talk* to this excerpt.

Table 7. Excerpt 1 from Finley's Discussion

Speaker	Turn	Talk Move Code
PST Finley:	You don't think you could improve at all?	*ES Design 2*
Ethan:	Well, I don't know. I mean 710 millivolts was pretty good. So, I guess it's possible, but I'm, I'm pretty satisfied.	
PST Finley:	Maybe we should try to improve our results. You never know, you could get even better number.	*ES Iteration*
Ethan:	Ooh. An even better number. Huh?	
PST Finley:	Mm-hmm.	None
Jasmine	Yeah	
PST Finley:	Have you guys talked about it at all? I'm sorry, Jasmine, go ahead.	*ES Progress*
Jasmine:	No, I, I, I'm glad you're - you're telling him to, to think about another one. We haven't really talked about it because, well … he didn't really talk about it before. And I had an idea to change blades and I think Ava's idea's a little different …	
PST Finley:	What were you thinking for your idea, Ava? Why don't you guys discuss it a little?	*ES Design 2* and *DS Prompting Student-to-student Talk*
Ava:	Well, you know, in our first design we, so we had to cut off the bottom corners. Did you see that we did that?	
PST Finley:	Mm-hmm.	None
Ava:	Yeah, it was so the blades could fit. Yeah. So the thing is, is that that made it, so I think our, our blades weren't really like a good shape, even though like we didn't, we were gonna to do a rectangle, but we had to chop those off. And then, yeah. I don't think that they're good that way.	

Note. ES = Engineering Support category, DS = Discussion Support category

In the next excerpt in Table 8, immediately after Ava's contribution at the end of Table 7, PST Finley used three discussion support moves (*DS Prompting Student-to-student Talk, DS Building on Student Ideas, and DS Allowing Student Talk*) to support students as they considered how to improve the blade shape (*ES D2*). Also in this excerpt, responding to Ava's mention of the "science stuff" followed by Jasmine looking at the science data, PST Finley stated that "it's a good idea to look at the data" (*ES Science*).

Table 8. Excerpt 2 from Finley's Discussion

Speaker	Turn	Talk Move Code
PST Finley:	Okay. So why don't you guys talk about what you guys can do to improve the blade shape?	*ES Design 2* and *DS Prompting Student-to-student Talk*
Ethan:	Well, I don't know. I think the blade shape is kind of cool. Nobody else in the class had that blade shape at all. So I was kind of hoping we stick with the blade shape. It's kinda got like, I don't know, like five sides to it. It's pretty cool looking.	
PST Finley:	What do you think about that, Ava?	*ES Design 2* and *DS Building on Student Ideas*
Ava:	Yeah, it might be. It is, I guess a neat shape. But um, like when you look at the science stuff that we did and you look at that, I guess that row that we call it, like mass distribution or something, but it's like the shape.	
Jasmine:	Oh yeah. I remember that. Yeah, let me look at my data to look at that too. Yeah. I need to look at that, too.	
PST Finley:	I think it's a good idea to look at the data.	*ES Science*
Ava:	Yeah, so the, the one that did the worst was the triangle that pointed like to the hub.	*DS Allowing Substantive Talk**
PST Finley:	Mm-hmm.	
Ethan:	Oh yeah. That one didn't do well at all.	
Ava:	Yeah. And that, that was kind of the worst. And it had the smaller part of the blade close to the hub and that's kinda like what our blade is like right now. I mean, it doesn't have a point, but it's like, if you cut the point off, so it's kind of like the worst shape.	
PST Finley:	Mm-hmm.	
Jasmine:	Oh. I see that. Right. I see what you mean I think. It's kinda like the worst one.	
Ethan:	Yeah. But it's, it's still a cool shape. I mean, Hmm. I guess I see it	
Jasmine:	I think I have an idea.	

Note. ES = Engineering Support category, DS = Discussion Support category.

* We consider "mm-hmm" as a continuer, not an interruption.

After the excerpt in Table 8, PST Finley asked Jasmine to share her idea. The idea Jasmine shared is to flip the blades around for D2, making it so the larger part of the blade would be close to the hub and the smaller part "pointing" outward. Jasmine, who sought compromise, offered that this addresses Ava's concern, which is rooted in the science data, and enables Ethan to keep the blade shape that he likes. Instead of evaluating Jasmine's idea, PST Finley asked: "What do you, Ethan and Ava, think about that? [To Jasmine] Why don't you ask your teammates?" This single prompt not only encouraged the team to focus on D2 (*ES D2*), but it also provided rich discussion support. It encouraged the team to build on Jasmine's idea and talk to one another and led to a back-and-forth discussion among all three team members (*DS Building on Student Ideas, DS Prompting Student-to-student Talk, and DS Allowing Substantive Talk*).

Ethan's contribution in this back-and-forth discussion was that by flipping the blades around, "they would run into each other again." Table 9 begins with PST Finley's response to this contribution, who asked the team if they have ideas to solve this problem and encouraged them to build on one another's ideas (*DS Building on Student ideas*). At the end of the excerpt and discussion, PST Finley encouraged the team to keep talking with one another about D2 and start sketching their D2 ideas (*ES D2*, *DS Prompting Student-to-student Talk*, and *ES Documentation).*

Table 9. Excerpt 3 from PST Finley's Discussion

Speaker	Turn	Talk Move Code
PST Finley:	So how can we solve that issue, Ethan? Do you have any ideas?	*ES Design 2*
Ethan:	Well … Jasmine was thinking she might want to add blades, but maybe we need to take away some blades …	
Jasmine:	Yeah, we have six blades right now … I was originally thinking we'd go to eight to catch more wind, but maybe that's not such a good idea. Maybe, if we went from six to four, they would all fit and then we wouldn't have to cut those corners off again.	
PST Finley:	Okay. What do you think about that, Ava?	*ES Design 2* and *DS Building on Student Ideas*
Jasmine:	Yeah, Ava, what do you think?	
Ava:	Well … that could work. So, we would have … four blades, we turn the blade around and they wouldn't run into each other. So maybe that would work. That could be our next idea. Yeah.	
PST Finley:	Okay	None
Ava:	That could work.	
PST Finley:	So why don't you guys talk a little bit more and see exactly what you want to do if you want to make any other changes or if everything else you want to keep the same and maybe sketch out a design for your D2.	*ES Design 2* and *DS Prompting Student-to student Talk* and *ES Documentation*

Note. ES = Engineering Support category, DS = Discussion Support category

PST Venice

PST Venice began the discussion with team AJEs Ago by focusing on how D1 performed (*ES D1*). PST Venice learned that Ethan felt that D1 was "amazing" and that he thought they were "done" with the design process. Jasmine and Ava said that they thought "we can improve it" (Jasmine) and "we should try some … different ideas" (Ava).

After this, Ava expressed a concern about D1, and PST Venice asked her to "tell me about it" (*ES D1*). As in the discussion that PST Finley facilitated, Ava described how their D1 blades pointed inward (pointing toward the hub) instead of outward (pointing away from the hub) – and that blades pointing inward "didn't do as well" according to the science data. PST Venice responded to this idea by first praising Ava's design thinking and use of the science investigation data (*ES Science*) and then asking what Jasmine and Ethan thought of the idea (*DS Building on Student Ideas*). See Table 10 for this response by PST Venice, Ethan's response, and the first of several instances of PST Venice evaluating D1 (*H Evaluate D1*).

Table 10. Excerpt 1 from PST Venice's Discussion

Speaker	Turn	Talk Move Code
PST Venice:	Jasmine and Ethan, what do you think of that? Ava I like your thinking there. I like how you're using the investigation and trying to see how we can learn from that. Jasmine and Ethan, do you have anything to add to that? Disagree?	*ES Science* and *DS Building on Student Ideas*
Ethan:	Uh, well, I mean, I I think the shape is - is pretty cool. I mean, it's a - it's a very creative, like a unique shape.	
PST Venice:	Agree.	*H Evaluate Design 1*

Note. ES = Engineering Support category, DS = Discussion Support category, H = Hindering category

After Ethan and Jasmine responded to what Ava was saying about how the D1 blades were pointing, PST Venice shifted the direction of the discussion to variables that the team had not yet discussed. This excerpt, shown in Table 11, includes multiple turns in which PST Venice (a) offered ideas for variables to change their planning for D2 (*H Offers Variables*), and (b) evaluated D1 (*H Evaluate D1*). In this excerpt, PST Venice challenged the students to guess which variable(s) should also be considered. Also, there is a turn in this segment in which PST Venice used some discussion and engineering support moves, tracking on ideas already brought up by team members (*DS Tracking Student Ideas*), asking them to reflect on D1 (*ES D1*), and urging them to consider how to create an improved D2 (*ES D2*).

Table 11. Excerpt 2 from PST Venice's Discussion

Speaker	Turn	Talk Move Code
PST Venice:	… You guys hit every - every little variable that you can, but I think we're missing one. Ethan, do you want to try and tell me what variable we think that we're missing taken considering of?	*H Evaluate Design 1* and *H Offering Variables*
Ethan:	Oh, well, I don't know. It might be, you know, one - one thing that we knew like wasn't the best, but we had to do it because we were running out of space was the … distance … between the - the hub and the blade. Like ours is like way far apart -	
PST Venice:	Right.	*H Evaluate Design 1*
Ethan:	And … it's not as good as it could be like. It's supposed to be like smaller than that, but we just were like we were running -	
PST Venice:	Right, so?	*H Evaluate Design 1*
Ethan:	- out of room, yeah.	
PST Venice:	Right, so, you guys are running out of room, so maybe that means that we should think about what we can do to our blades. Ava brought up a good point about changing our blade shape. I think that's a good idea to maybe think about so we can tweak other things like the number of blades and the distance of the hub like you were talking about Ethan. But what I want to ask you guys is: Why do you think that lead to a lower voltage? How do you think we can improve?	*DS Tracking Student Ideas* and *ES Design 1* and *ES Design 2* and *H Offer Variables*
00:04:46 Ava	Uhm well. I think. I don't know. I think it's like harder for the - for the turbine to like spin when things are kind of like out. Like far away.	
PST Venice:	Right.	*H Evaluate Design 1*

Note. ES = Engineering Support category, DS = Discussion Support category, H = Hindering category

After the transcript excerpt in Table 10, the team discussed the idea of rotating the blades so that the wider end was closer to the hub and the narrower end was pointing away from the hub. PST Venice responded to this idea by praising it (*H Evaluate D2*), saying that the D1 voltage output was "amazing" (*H Evaluate D1*), and explaining how improvements are "meant to benefit your entire project" (*ES Iteration*). As shown in Table 12, after Jasmine's reply in which she expressed concern about the blades running into one another, PST Venice offered the idea to the team to reduce the number of blades (*H Offer Ideas*), then acknowledged it was "up to you guys" to make decisions about D2.

Table 12. Excerpt 3 from PST Venice's Discussion

Speaker	Turn	Talk Move Code
PST Venice:	Yeah, and that's a very easy fix for you guys to have and it could completely change your whole average for voltage, I think that's a really good idea. Is there anything else that you guys think could do to improve your voltage? I know, Ethan, you thought that it was amazing, and it was amazing. And I don't want you guys to think that improvements are corrections. Improvements are meant to benefit everybody and benefit your entire project as a whole. So do you think that right now our design is perfect?	*H Evaluate Design 1* and *H Evaluate Design 2* and *ES Iteration*
Jasmine:	Oh no, I don't think it'll be perfect, but it could be better. I mean, I think it would be better if we flip those around, but the only thing I'm wondering about is if we flip them around … and kept all of them there. We're gonna have the same problem that we had before where the blades are gonna run into each other.	
PST Venice:	I'm glad - I was just about to bring that up to you guys. I'm glad you thought about that. So maybe. Maybe let's think about, like, lessening the number of blades because if they're so close together then they might knock into each other.	*H Offer Design Ideas*
Ethan:	Yeah, I see where you're going. So you're saying like instead of 6 like maybe four or something?	
PST Venice:	That's up to you guys to decide. I'm just here to try and show you how we can change our ideas a little bit to make them have better outcomes.	None

Note. ES = Engineering Support category, H = Hindering category

After the excerpt in Table 12, the team decided to reduce the number of blades, which Ethan suggested also allows the team to reduce the distance between the blades and the hub. PST Venice indicated agreement with this decision and said it is like "killing two birds with one stone" (*H Evaluate D2*). PST Venice wrapped up the discussion by asking the team to recap their decisions, restating some of those decisions (*DS Tracking Student Ideas*), praising both D1 and D2 (*H Evaluate D1 and Evaluate D2*), and asking the students to document their D2 ideas in their engineering notebooks (*ES Documentation*).

Discussion and Conclusion

Diagnostic troubleshooting is an essential part of the engineering design process and one that is important for students to engage in productively as they build towards becoming informed designers who can create future design iterations based on previous test results. In elementary classrooms, teachers have a critical role to play in supporting students to engage in productive diagnostic troubleshooting. They can serve as a supportive "other" for students within social constructivist views of learning [13, 14], ideally providing just enough and not too much support for students to engage in diagnostic troubleshooting as a team [1, 2]. However, few empirical research studies have examined how teachers do so. This study aimed to contribute to this small body of research by examining the nature and frequency of the talk moves that elementary PSTs use to engage students in diagnostic troubleshooting while facilitating a discussion with three students in a simulated classroom.

The main takeaways from our work are that the participating PSTs used a range of talk moves that may have supported and hindered student engagement in diagnostic troubleshooting. Specifically, the PSTs used talk moves that likely:

(1) supported big ideas in engineering education about design thinking, scientific evidence that informs engineering decision making, iteration, and documentation;
(2) supported student engagement in discussion with the teacher and with one another by encouraging teamwork, tracking and building on student ideas throughout the discussion, and prompting and allowing student-to-student talk; and
(3) hindered student engagement in diagnostic troubleshooting when the PSTs evaluated students' design ideas, identified variables to change from the first to the second design, and suggested specific design ideas for the second design.

All but two of the 19 PSTs used talk moves in each of these categories (i.e., Engineering Support, Discussion Support, and Hindering).

Most of the talk moves that the PSTs used when facilitating the discussion in the simulated classroom were ones that would be likely to support student learning during engineering design challenges. Teacher educators can encourage PSTs to use these supportive talk moves as they engage their future (real) students in diagnostic troubleshooting. Similar to the research we cited previously on talk moves within engineering education [31, 32], these talk moves were ones that support student sensemaking, promote student agency, and aim to ensure all student ideas are included in the discussion. It is encouraging to observe how PSTs began with an ability to use talk moves that are likely to be successful in supporting student agency and sensemaking. [Note that some, but not all, of these talk moves may have been encouraged by the PSTs' previous simulated discussion experience in their one-on-one discussions with avatar Savannah about her idea fixation during brainstorming (e.g., prompting students to reason about a design)]. It would be important for teacher educators to recognize PSTs' existing instructional strengths and encourage PSTs to continue engaging in these types of talk moves when supporting students' diagnostic troubleshooting during engineering design.

In addition to these strengths, results also suggested that teacher educators help PSTs learn to avoid the talk moves we coded as potentially hindering student engagement in diagnostic troubleshooting—moves that represented one in five of all moves we coded across the transcripts. The most common way that PSTs tended to hinder the students' engagement was by evaluating the students' ideas, instead of providing opportunities for the students to first consider and share their own thinking and reasoning about others' ideas. Teachers evaluating student ideas within discussions is common in K-12 classrooms [22, 23]. In future learning opportunities, it would be important for teacher educators to help PSTs both (a) identify when and how they might be hindering students' engagement in productive diagnostic troubleshooting and (b) determine and practice other approaches they could use to help students be the ones who evaluate each other's ideas. Doing so would help to shift PST talk moves away from conservative talk moves and toward more inclusive ones that provide opportunities for all students to share and respond to each other's ideas [32-34].

These findings contribute to a small but growing number of studies that use digital teaching simulations to study how educators facilitate engineering discussions and the nature of the talk moves they use to support student engagement and learning [38-43]. Future research should examine how PSTs apply the talk moves they use in simulated classroom environments to their work with students in real classrooms—first within their field placements as part of their teacher education program and then within their initial teaching assignments as teachers of record. Another promising research area would be to investigate how PSTs navigate and learn from these kinds of simulated discussions over time, as they have multiple opportunities to try out facilitating and reflecting on these discussions across several instructional cycles. Finally, it would be important to research how these types of practice-based learning opportunities are integrated within varied teacher learning settings, including teacher education courses, district-based professional development, and professional learning communities. Doing so would allow the field to better understand the key factors that support and hinder teacher learning when using these technological tools within teacher education.

Like other studies, this one has a few limitations. First, this qualitative study investigated the talk moves used by 19 PSTs at one university. It is possible that different patterns could be identified if this study had been conducted at a different university or with a different set of PSTs. We leave it to future research to determine to what extent the patterns shown in these PSTs' talk moves aligns with other PST populations and university contexts. Second, while each PST engaged in the same discussion with the same three students who had completed the same engineering design, it is possible that the sim may have made mistakes that could have impacted the talk moves that the PSTs used when facilitating their discussions. While the use of structured and intensive sim training likely reduced mistakes made by the sim, mistakes are inevitable; in future research it would be beneficial to examine the extent and potential impact of those mistakes. Finally, this study focused on the talk moves that PSTs used within simulated classroom discussions, not real classrooms with elementary students. While the PSTs in this study did not indicate that they would use different talk moves if the setting had differed, this would be a future research area to better understand and investigate. It would also be useful to examine to what extent the PSTs' learnings from these simulation-based experiences were transferred to their course field experiences.

We look forward to more work in the engineering education community being directed towards how teachers support students in discussion throughout the design process. We will continue to explore teacher talk moves in engineering education, including from teacher engagement in digital teaching simulations like Mursion® but also within simulations powered by generative artificial intelligence instead of sims.

Acknowledgments

We would like to thank the PSTs who participated in the study. (This work was not funded.)

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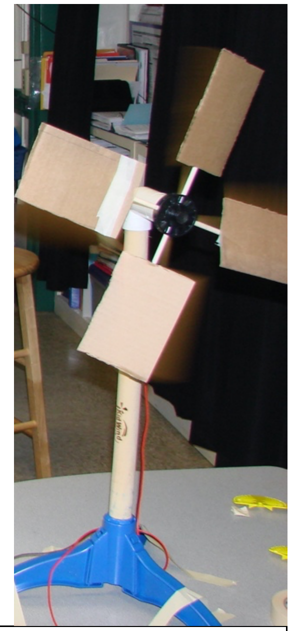
Appendix

Simulated Engineering Teaching Experience Scenario
Diagnostic Troubleshooting and Improvement
in a Wind Turbine Blade System Design Challenge

Background



The students in your 8th-grade physical science class were engaged in a wind turbine design challenge. The goal of the challenge was to create blades for a model wind turbine out of dowels and cardboard that would be attached to a circular black hub. The hub was directly attached to the turbine's generator, which was atop the model turbine tower (see image). When placed in front of a fan, the blade system and hub would spin. This caused the generator shaft to spin, producing electricity. Electrical output was measured in millivolts (mV).

Prior to the challenge, your students conducted scientific investigations of the relationship between different blade system variables and voltage output. Variables included number of blades, blade angle, distance between hub and blade, blade width, blade length, and mass distribution (i.e., if there was more mass of the blade closer to the hub or farther away from the hub). Each group of students investigated three trials of three different conditions of one variable, calculating an average output voltage for each condition. Groups shared the following evidence and claims based on the group investigations (see table). The claims were accurate reflections of the evidence that the groups gathered.

Group	Variable	Evidence [a]	Claim
1	Number of Blades	3 or 4 blades had an average output voltage of 510 mV; voltage for 2 blades was 477 mV	3 or 4 blades had more output voltage than 2 blades [d]
2	Blade Angle	15° had an average output voltage of 610 mV; 30° was 510 mV; and 45° was 280 mV	Lower blade angle, more output voltage
3	Hub to Blade Distance	0.5 cm had an average output voltage of 544 mV; 2 cm was 510 mV; and 3.5 cm was 340 mV	Smaller the distance, more output voltage
4	Blade Width [b]	8 cm width had an average output voltage of 527 mV; 6 cm was 510 mV; 4 cm was 407 mV	6 or 8 cm blade width had more output voltage than 4 cm [d]
5	Blade Length [c]	9 cm length had an average output voltage of 607 mV; 12 cm was 510 mV; 15 cm was 380 mV	Shorter the blades, more output voltage
6	Mass Distribution	Triangular blade with wider part close to hub had an average output voltage of 553 mV (see image); rectangular blade of same mass was 510 mV; triangular blade of same mass flipped around with tip close to hub was 510 mV 	More blade mass closer to the hub, more output voltage

Note: All blades were rectangular except when examining mass distribution.

[a] Only average output voltage is shared here for brevity. Differences of 30 mV or less were not considered significant due to error in the system. [b] Since length was held constant, the mass also increased as width increased. [c] Since width was held constant, the mass also increased as length increased. [d] These claims were written this way because two conditions (3 or 4 blades; 6 or 8 cm) had similar output voltages, thus, for example, it was not accurate to say that the more blades or the smaller width, the more voltage output across all conditions.

Design Creation and Testing

After brainstorming, idea selection, and planning, each team created their first blade system (Design 1 or D1). Each team was comprised of two or three students. When each team was ready to test D1, you helped the team affix their hub with attached blades to the generator. Each team conducted three trials in which they turned the fan onto the highest setting, read the voltage output after the blades spun for 20 seconds, and then turned off the fan. They used the voltage output from the three trials to calculate an average voltage output for D1.

The team of focus in this SETE is Ava, Jasmine, and Ethan. They called themselves team "AJEs Ago" (pronounced, "ages ago"), with AJE representing the first letters of their names. This team created a blade system with the following features for the following reasons:

- 6 blades - more blades seemed like it would create more output voltage and six blades would also look cool
- 15 degrees - that was the lowest angle and lower angles create more output voltage
- 8 cm wide - that was the lowest width but we didn't want it too narrow
- 6 cm long - we thought we would make ours extra short since shorter blades created more output voltage
- 3 cm distance between hub and blade – we needed to use this to get the blades far enough apart from one another
- Rectangular shape (with corners cut out) – rectangles were easier to make and there wasn't much of a difference between triangle shapes and rectangle shape in our science investigation; we did have to cut off the bottom corner so all the blades would fit

The average output voltage that they got for this design was 710 mV

Considering Design Improvements

After testing, you asked teams to review their D1 testing results and D1 decisions and consider how they would change their D1 blade systems to improve them since their next step was to plan and create design 2 (D2). After you finished helping each group test their D1 wind turbine blade systems, you started checking in with each table group about their improvement ideas.

At one table sat both Team AJEs Ago (Ava, Jasmine, and Ethan) team "Sav-Dev" (Savannah and Dev). While Savannah and Dev were busy talking to one another and writing in their engineering notebooks, Ava, Jasmine, and Ethan were not interacting with one another and didn't seem to be writing in their notebooks.

Your Team Discussion with Team AJEs Ago

You will engage in a discussion with Ava, Jasmine, and Ethan only while Savannah and Dev, at the same table, continue to document their ideas and talk to one another. Your goal in this short discussion is to:

(1) Elicit from Ava, Jasmine, and Ethan the results of their D1 testing, their ideas that went into D1, and their current ideas about how they might improve their design (to plan for D2); and
(2) Support this team to engage in diagnostic troubleshooting and determine productive ways to improve their design.

Note that your goal is not to suggest specific design ideas, but rather to encourage them to look at their D1 and the scientific investigations so that they can determine how to improve.

You have up to 12 minutes.

Meet Team AJEs Ago

About Ava

Ava is bright and likes to be a leader. However, she can be easily frustrated with her peers for not moving as quickly as she does in her thinking; she can also be insensitive. She is an extrovert. Ava responds well to praise and positive attention. Ava has high standards for the work she produces. Working on a team is not Ava's favorite part of engineering since she must share in decision-making with her peers. Ethan, in particular, tends to frustrate Ava. (Image and elements of Ava's description are from Mursion®.)

About Jasmine

Jasmine is bright and performs well in school. She is passionate about science. She is a people pleaser, seeking acceptance from others, especially from Ava. Jasmine avoids conflict and tries to find a middle ground when in conflict. Since engineering sometimes involves teammates stating claims about decisions (like how to improve), it stresses Jasmine out a bit since that feels like conflict to her. That said, she can be helpful when it comes to convergent thinking like finding consensus. (Image and elements of Jasmine's description are from Mursion®.)

About Ethan

Ethan is a playful extrovert, often cracking jokes in class. He has difficulty paying attention when work is challenging or, alternatively, boring. He seeks approval from his peers, is supportive, and tries to understand others' perspectives. He is confident, even when he is not right. He is easily satisfied with the engineering solutions he and his team devise. (Image and elements of Ethan's description are from Mursion®.)