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Middle School Preservice Teachers' Discussion Prompts to Help a Student Avatar Overcome Idea Fixation during Brainstorming (Fundamental)

Pamela S. Lottero-Perdue Ph.D., Towson University

Pamela S. Lottero-Perdue, Ph.D., is Professor of Science and Engineering Education in the Department of Physics, Astronomy & Geosciences at Towson University. She has integrated engineering into courses for PreK-8 teacher candidates, developed and directed a graduate STEM program for PreK-6 teachers, and partnered with teachers to implement PreK-8 science-integrated engineering learning experiences. She has authored numerous engineering-focused teacher practitioner articles, chapters, and research articles, and presents her research regularly through the ASEE Pre-College Engineering Education Division, a division she has chaired. Her current research includes investigating how K-5 students plan, fail, and productively persist, and how simulated classroom environments can be used to help pre-service and in-service teachers practice facilitating discussions in science and engineering.

Dr. Jamie Mikeska,

Jamie Mikeska is a Research Scientist in the Student and Teacher Research Center at Educational Testing Service (ETS). Jamie completed her Ph.D. in the Curriculum, Teaching, and Educational Policy graduate program at Michigan State University in 2010. Her

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Introduction

This study examines the ways in which 18 middle school pre-service teachers (PSTs) enrolled in an engineering teaching methods course facilitated discussions with a student who is experiencing idea fixation during brainstorming. This learning opportunity was the PSTs' first discussion with a student experiencing idea fixation, and the student, Savannah, is a student avatar in the Mursion® simulated environment. In what follows, we begin by discussing brainstorming as a key part of engineering design, as well as the challenge of idea fixation. We then share how simulations can be useful tools to study PSTs' discussion facilitation, as well as to enable PSTs to practice facilitating those discussions prior to working with real students. We share our methods and findings, which suggest that without prior pedagogical instruction, PSTs use prompts in their discussions that have the potential to both support and hinder students in their brainstorming efforts. We conclude with a discussion of findings, as well as implications for future research and teacher education.

Brainstorming

Brainstorming during engineering design involves generating multiple possible ideas to solve a problem and occurs prior to the selection and development of a formal plan in engineering design processes. According to Crismond and Adams, informed designers—i.e., those whose "level of competence lies somewhere between that of the novice and expert designer" (p. 743)—use divergent thinking to generate as many ideas as possible [1]. The underlying idea of brainstorming is that thinking of more ideas will ultimately lead to a better idea to be realized later in the design process [2]. For example, Kudrowitz and Dippo summarized findings of their empirical work on brainstorming, or ideation, as follows: "to get more original solutions [to a problem], one must push past and build upon the ideas generated first to arrive at the less obvious ideas and association" (p. 15) [3].

Despite brainstorming being recognized as a key part of engineering design [1, 4, 5], it is understudied in the engineering education literature and underemphasized within engineering education [6]. Some literature has suggested how students can be supported as they engage in brainstorming or divergent thinking. Osborn devised four rules for brainstorming [2]. The first two were to conceive of as many ideas as possible and refrain from critiquing those ideas as they emerge. Two other rules suggest that ideas might emerge from combining other ideas or thinking of unusual ideas. Crismond and Adams offered similar suggestions in the form of teaching strategies, including that ideas should be sketched and students should be provided with a rationale as to why it is important to brainstorm multiple ideas [1]. Bartholomew and Ruesch offered that teachers should refrain from providing examples of ideas and should encourage wild or playful ideas as students brainstorm [7]. Clancy's recent dissertation identified "influential factors that helped facilitate or hinder divergent thinking" among a sample of high school and college-aged engineering students [6]. One of the factors that facilitated divergent thinking was explicit encouragement of divergent thinking by instructors; the reverse was also true in that a

lack of encouragement and structural support for divergent thinking were factors that hindered productive brainstorming. This finding is consistent with Mentzer and colleagues' suggestion that "learning to develop innovative ideas through brainstorming is a skill that can be fostered, practiced, and improved with repeated experiences " (p. 9) and with support from instructors [8].

Idea Fixation

In contrast to informed designers, beginning designers may "work with few ideas or just one idea, which they can get fixated or stuck on, and may not want to change or discard" (p. 748) [1]. The term for getting stuck like this is "idea fixation." Fixation on a designer's first idea about how to solve a problem can occur when designers are given an example problem or when their first idea is self-generated [9, 10]. This is a type of idea fixation that Youmans and Arciszewski called conscious blocking, which we address in the present paper; other types include unconscious adherence and intentional resistance [11].

Others have considered ways to help mitigate idea fixation, including teaching strategies to support divergent thinking as described in the previous section [1, 2, 6-8]. Hwang and colleagues also created a visualization tool for beginning designers to help them "perceive and predict the occurrences of design fixation" [12] (p. 1). Also, Leahy found that the use of design heuristics—e.g., providing designers with cards with titles such as "add levels," "reduce material," "rotate," or "simplify" (p. 5)—enabled more ideas to emerge in the brainstorming process [9].

Using Simulations in PST Education for Practice and Research

One goal of PST engineering education is to prepare PSTs for instances of idea fixation within their future students—learning to respond in a way that supports students' opportunities to engage in the brainstorming process as informed designers. An approach to helping PSTs learn how to engage their students productively in the brainstorming process is to use approximations of practice where they can try out this teaching practice, but in a setting of reduced complexity [13]. Digital teaching simulations have been increasingly used in teacher education settings to provide opportunities for PSTs to engage in approximations of practice where they can develop specific instructional skills, such as learning how to facilitate discussions, elicit student thinking, and manage classroom behavior [14-16].

In digital teaching simulations, PSTs can interact with one or more digitally animated student avatars who can respond in real time to the PST and to each other. For example, several studies have used Mursion's upper elementary simulated classroom, which includes five interactive student avatars played by a highly trained actor (a simulation specialist or "sim"), as a practice space for PSTs to try out instructional practices within mathematics, science, and engineering education [17-20]. There is a growing body of empirical evidence across studies that suggest that digital teaching simulations can be integrated into teacher education courses and used productively to improve PSTs' teaching skills, instructional beliefs, and understanding of key constructs [21-23]. In this study, we used Mursion's middle school classroom as the practice space in which the PSTs practiced facilitating a discussion with a student who is experiencing idea fixation during brainstorming.

Research Question

The research question for the present study is: Prior to PSTs receiving methods instruction about how to support students experiencing idea fixation, what prompts do PSTs use that are likely to support or hinder one student's engagement in brainstorming?

Methods

Participants and Course Context

Study participants were 18 middle school science education PSTs enrolled in an engineering teaching methods course at Towson University in 2021, 2022, or 2023, and who consented to participate. There was an 86% participation rate across the three sections. This study has been approved by the first author's Institutional Review Board (IRB).

The course is offered once per year in the fall. PSTs typically take the course in their second or third year and few have had prior teaching experiences; none had prior teaching experience teaching engineering. The simulated discussion with Savannah was a course assignment during the first third of the course and was the PSTs' first engineering teaching experience. Prior to it, the PSTs engaged in brainstorming themselves as learners, engaged in a class discussion about idea fixation, and read a short article about idea fixation [7]. We did not gather demographic data from the participants. The most recent race/ethnicity student demographics at the university are: 40% White, 33% African American/Black, 11% Hispanic or Latine/x, 6% Asian, 5% two or more races, 1% international, and 4% other.

Simulation Scenario

Previously, we developed a two-page simulation scenario document (see Appendix) for PSTs to use to facilitate a discussion with a Mursion® middle school student avatar, Savannah, who was experiencing idea fixation [24]. The document situates the PST as the teacher of Savannah and her classmates. In addition, included in the document was the following background information:

- Prior to the engineering challenge, the class had scientifically investigated the relationship between six different wind turbine blade system variables (e.g., number of blades) and output voltage; a table of claims and evidence was included in the document.
- After introducing the challenge, the teacher (the PST) had asked each student in the class to brainstorm at least two ideas for a wind turbine blade system that would have the highest output voltage possible.
- While monitoring students as they individually brainstormed, the teacher (the PST) noticed that Savannah only sketched one idea on the brainstorming page of her notebook.
- Savannah is a good student who is a bit of a perfectionist and has trouble with open-ended activities like design challenges; her picture was provided so PSTs knew what to expect (Figure 1).
- Savannah's brainstorming page included just one idea; an image of this brainstorming page was provided in the document (Figure 2).

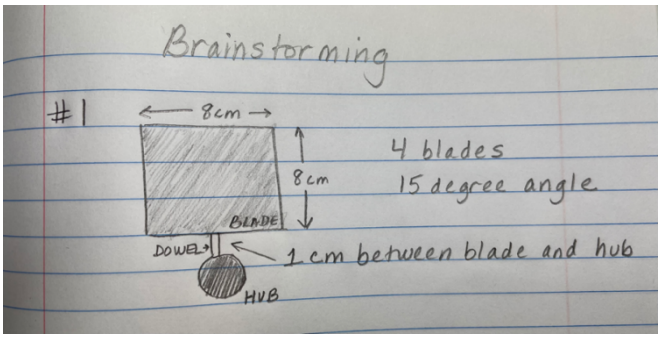
The document also informed the PSTs of the goals for the discussion as Savannah's teacher. These were to (1) get Savannah's attention when the PST first sees Savannah on Zoom, (2) elicit ideas from Savannah about her first brainstormed idea, and (3) support Savannah to add at least one new idea to her brainstorming page. The discussion was to be about 7 minutes in duration.

An additional aspect of the simulation scenario is worthy of note. The sim who plays Savannah is also the first author and the course instructor. The first author, who has received extensive training to be a sim for the Mursion® middle school and other classrooms, did not reveal this to the PSTs until the very end of the course. The PSTs were informed that the university uses Mursion® and employs people trained by Mursion® to serve as sims.

Figure 1. Savannah

(Used with permission, Mursion ®)

Figure 2. Savannah's Brainstorming Page



Data Collection

About two weeks prior to facilitating their individual discussions with Savannah, the first author as the course instructor worked with all PSTs in the course to identify times for them to facilitate their discussions with Savannah. Sessions were scheduled to occur within a one-week period. About one week prior to the first scheduled session, PSTs received the simulation scenario document, which they used to prepare for the session.

When each PST entered the Zoom session at their scheduled time, they saw Savannah sitting at her desk writing. It was up to the PST to get her attention and begin the discussion. Discussions ranged from 5 to 9 minutes (M = 7) in duration. Zoom sessions were video recorded and we used the auto-transcription service from Zoom to create transcripts, which we then reviewed and corrected, as needed. Videos and transcripts were not used for research purposes until after grades were submitted at the end of each semester, as per the consent process approved by the IRB and given that the instructor was also one of the two researchers of record.

Data Analysis

We used conversational analysis of the 18 discussion transcripts [25], coding each PST turn in the discussions. By turn, we mean the utterance (i.e., uninterrupted talk) by the PST that is preceded and/or followed by an utterance from Savannah. We began with a prior codebook which we had used to code discussions with Savannah for the 2021 participants only [24]. The two co-authors group-coded four transcripts, two from the original set and two others selected

randomly. This resulted in some changes to our codebook. We then double-coded four additional transcripts, again chosen at random. We reconciled differences and again updated our codebook. Finally, the first author coded the remaining transcripts, highlighting areas of ambiguity to discuss with the second author; those areas were reconciled. We used qualitative content analysis to investigate the frequency with which we applied codes and codes across the PSTs [26].

The two major codes in our final codebook were "supporting" and "hindering." The first refers to those prompts that PSTs used that were likely to support Savannah in brainstorming (see Table 1). These were based on the role of brainstorming as a part of engineering design as described in the literature [1-3, 6-8], including that it is the student's—in this case, Savannah's—role, not the PST's or teacher's role, to generate ideas.

Table 1. Supporting Prompt Codes

Code Name	Code Description: PST …
Idea 1	Asks Savannah to share details or provide reasoning about Idea 1
Idea 2	Asks Savannah about what to include for Idea 2 in general or in comparison with Idea 1
Science	References the scientific data or asks Savannah to consider, share, restate, or reference evidence/data or claims from the scientific investigations
Brainstorming	Asks Savannah how brainstorming is going or where she is in the brainstorming process
Progress	Asks Savannah to explain why she has one idea or share how Idea 2 is coming along
Multiple Ideas	Suggests to Savannah that it is important to have multiple ideas when brainstorming and/or provides reasoning about why this is good practice
Creative	Encourages Savannah to be creative or applauds Savannah's creativity

Hindering codes were applied to instances in which PST prompts may have hindered Savannah's engagement in brainstorming (see Table 2). Collectively, these were instances in which the PST may have evaluated the quality of either Savannah's first idea in her notebook or the quality of a proposed second idea, offered up information about variables or design ideas for Savannah to consider for her second idea, or somehow misrepresented the brainstorming part of the design process. These hindering codes are consistent with recommendations in the literature to refrain from engaging in critique during ideation and for the instructor to avoid providing ideas [2, 7].

Table 2. Hindering Prompt Codes

Code Name	Code Description: PST …
Evaluate Idea 1	Evaluates Idea 1 or aspects of Idea 1, sharing strengths or weaknesses of this idea
Evaluate Idea 2	Evaluates Idea 2 or aspects of Idea 2, sharing strengths or weaknesses of this idea
Offer Variables	Identifies which variables (e.g., number of blades) Savannah should focus on for Idea 2
Offer Design Ideas	Suggests specific design ideas for Idea 2 (e.g., to use 3 blades, use a certain shape, etc.)

Relevance to brainstorming needed to be apparent and explicit within turns to be coded as supporting or hindering. General turns by the PST (e.g., "How are you doing?" or asking Savannah to continue if there was interrupted speech) were labeled as "no code."

Findings

We begin by summarizing the frequencies of supporting prompts across PSTs and codes, then do the same for hindering prompts. Then, we share the range of supporting and hindering prompts for each PST, providing examples of two PSTs who varied in their use of these prompts.

Supporting Prompts

Altogether, we applied 179 supporting codes across the 18 PSTs. Table 3 provides examples of each code from the data. Table 4 summarizes frequencies with respect to participants and codes. The two most frequently applied supportive codes were *Support Idea 2* and *Multiple Ideas*, used by 94% and 100% of PSTs, respectively, and applied 59 and 47 times, respectively, across PSTs.

Table 3. Examples of Supporting Prompts

Code	Example(s)
Idea 1	"How did you go about choosing your dimensions and, like, your angles? What kind of things were you thinking about?" (PST 6)
Idea 2	"So - Maybe pick maybe pick one or two things that change up with this design that's different from the first one." (PST 4)
Science	"Do you remember the chart of data that we figured out from the investigation? So why don't we look back at that?" (PST 10)
Brainstorming	"So I wanted to talk to you about your brainstorming idea that you've had." (PST 19)
Progress	"Have you thought about, like, do you have a second idea on your page or no?" (PST 18)
Multiple Ideas	"So if you have only one idea and you only use one idea, then how are you supposed to know that's the best idea if you haven't made a second one to compare it to?" (PST 16)
Creative	"Like, just be creative with it. Because you're so creative with like your first idea with the square, I think now it would just be super cool to try out with the whole class." (PST 8)

Table 4. Supporting Prompts: Frequencies per PST and Code

Code	Codes per PST Participant (n = 18 participants)				Total Codes Across Participants (n = 179 supporting codes)	
	Number of PSTs	Percentage of PSTs	Minimum Codes per PST	Maximum Codes per PST	Number of Codes across all PSTs	Percentage of Supporting Codes
Idea 1	12	67%	0	3	26	15%
Idea 2	17	94%	0	7	59	33%
Science	8	44%	0	11	27	15%
Brainstorming	3	17%	0	1	3	2%
Progress	10	56%	0	1	10	6%
Multiple Ideas	18	100%	1	6	47	26%
Creative	5	28%	0	1	7	4%

Hindering Prompts

Altogether, we applied 142 hindering codes. See Table 5 for examples of hindering prompts from the data and Table 6 for a summary of frequencies with respect to PSTs and codes. The two most frequently applied hindering codes were *Evaluate Idea 1* and *Offer Variables*; each were applied to the transcripts of 89% of PSTs and were represented within 34% and 40% of all hindering codes, respectively. Almost exclusively, the type of evaluation that occurred with respect to *Evaluate Idea 1* (or *Evaluate Idea 2*) was when the PST shared that Savannah's idea was great or fantastic or some other type of praise. Although well intended, this may not be helpful with respect to focusing on brainstorming multiple ideas and letting Savannah determine the quality of her ideas without influence from the teacher.

Table 5. Examples of Hindering Prompts

Code	Example(s)
Evaluate Idea 1	"The first one is a great one to try out …" (PST 1)
Evaluate Idea 2	"I like the idea of a triangle. I say go with that." (PST 9)
Offer Variables	[After Savannah says that she likes her first idea.] "OK, I mean have you, have you considered maybe the number of blades might affect it differently?" (PST 13)
Offer Design Ideas	"So if you're gonna keep the 15 degree angle, because you really think that you're really confident that the 15 degree angle is going to be what you want … but that means you need to change either the amount of blades that you have, or you need to change the shape of the blade. You know you can make it possibly a triangle. You could make it, you know, longer in height. Or you can make it thinner in width …" (PST 18)

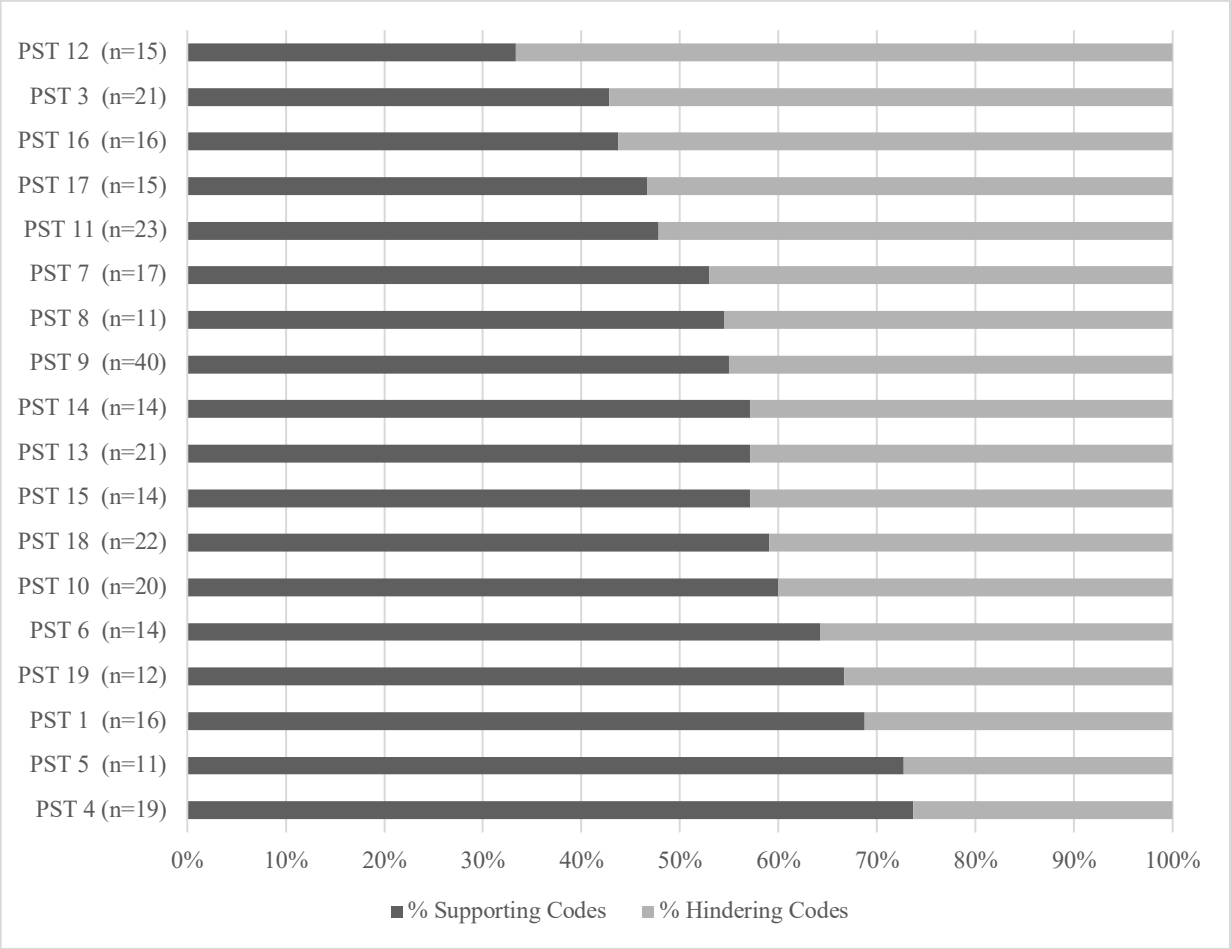
Table 6. Hindering Prompts: Frequencies per PST and Code

	Codes per PST Participant (n = 18 participants)				Total Codes Across Participants (n = 142 hindering codes)	
	Num PSTs	Per PSTs	Min Codes per PST	Max Codes per PST	Total Num Codes across all PSTs	Per of Total Supportive Codes
Evaluate Idea 1	16	89%	0	8	48	34%
Evaluate Idea 2	11	61%	0	5	20	14%
Offer Variables	16	89%	0	8	57	40%
Offer Design Ideas	8	44%	0	4	17	12%

Hindering and Supporting Prompts Across PSTs

All PSTs used both supporting and hindering prompts, albeit to different extents. Figure 3 reflects the percentage of supporting and hindering prompts for each participant. PST 4 had the highest ratio of supporting to hindering codes, whereas PST 12 had the lowest. See Table 7 for details about their transcripts, as well as the minimum, maximums, and means across PSTs.

Figure 3. Percentage of Hindering and Supportive Codes for Each Participant



Note. Number in parentheses next to each participant is the total number of supporting and hindering codes applied.

Table 7. Sample PST Transcript Data

	Turns	PST Words Uttered	Duration (minutes)	Total Number of Codes	Number of Supporting Codes	Number of Hindering Codes
PST 4	18	317	6.4	19	14	5
PST 12	21	879	6.7	15	5	10
Mean across PSTs	21.3	631.4	6.9	17.8	9.9	7.9

High Supporting PST 4

Overall, we coded 14 supporting and 5 hindering codes within PST 4's transcript. The supporting codes included the following in order: (1) *Support Idea 1*, (2) *Science*, (3) *Multiple Ideas*, and (4) *Support Idea 2*. The hindering codes were *Evaluate Idea 1* and *Evaluate Idea 2*. There are three distinct segments of PST 4's discussion. The first occurred during the first three minutes of the discussion and focused on Savannah's first brainstormed idea. This segment involved PST 4 asking Savannah about her first idea and referencing the scientific data in support of that idea (supporting codes, *Support Idea 1* and *Science*) and praising Savannah's first idea (hindering code, *Evaluate Idea 1*). See Table 8a for this exchange. We indicate supporting codes with "(S)" and hindering codes with "(H)". In turns with multiple codes in this and other tables, we separate turn segments in the row and align them with corresponding codes.

Table 8a. PST 4 Transcript Segment 1: Focus on Idea 1

Speaker	Turn	Code
PST 4	Um so it looks like here that you made a great design.	(H) Evaluate Idea 1
Savannah	Oh, thank you I'm very proud of my - my design, I really liked it a lot.	
PST 4	Yeah, it looks very nice.	(H) Evaluate Idea 1
	So, I just want to walk you, through your kind of process when making this design on, so what made you go with like the four blades instead of … maybe another number of blades.	(S) Support Idea 1
Savannah	Um well I just I think I like the way that the four blades worked, I mean they look kind of cool because I think it'll be like symmetric kinda. Yeah for four blades and they each have four sides, so I think that's pretty cool.	
PST 4	Yeah no, I think I think that's a great idea and it's going to look cool because, as you said, it's gonna be symmetrical.	(H) Evaluate Idea 1
	So … it looks like your blade you went with an eight-centimeter length and width. So you kind of made it like a square. Um, so why, why did you go with that kind of shape instead of like a like a triangle or so - let's go with that one?	(S) Support Idea 1
Savannah	Well, I so - one thing is that we didn't actually test a square when we did our science [investigations]. So, we did a rectangle and we did some triangles, but I wanted to see what a square would look like and the width at eight centimeters … and the eight centimeters yes, right here, it is the best for output voltage for the width. And I think it'd be pretty good to for the height and since I wanted a square anyway it needed to be the same …	
PST 4	That's good that's good.	(H) Evaluate Idea 1
	So you basically just looked at the data, saw that 8 centimeters was the best, [then] picked that. I mean I probably would have done the same thing. Yeah, so I think that's good idea.	(S) Science
Savannah	Yeah I love my idea.	
PST 4	Yeah, yeah. That's great, um, so one other thing I wanted to say is the angle. So 15 degrees, um, what - what made you go with 15 and not something that was maybe a little bit more like 30 or 45?	(S) Support Idea 1
Savannah	Well, I was hoping, you would ask that because I was part of a team that did the angle, when we did our scientific investigations. And it was so cool to see that we thought 45 was going to do really well, but it didn't so 15 to the best.	
PST 4	Okay, so you just went off the data and basically just - all that.	(S) Science

In the next segment (Table 8b), PST 4 shifts into encouraging Savannah to consider having more than one idea. PST 4 begins with confirming that "it makes sense" to PST 4 why Savannah chose a 15 degree angle. PST 4 then praised Idea 1 again (hindering code, *Evaluate Idea 1*) and shared an argument for why more than one idea is preferrable (supporting code, *Multiple Ideas*). This segment was slightly over one minute in duration.

Table 8b. PST 4 Transcript Segment 2: Multiple Ideas

Speaker	Turn	Code
PST 4	Yeah, I mean that makes sense … I agree with that. Um, alright so great first idea. I love it.	(H) Evaluate Idea 1
	Um, one thing I will suggest is maybe making a couple more maybe, at least, just like one more brainstorming idea, um, just to get some different ideas um.	(S) Multiple Ideas
Savannah	What if – what if I really like this one? I mean I really like it so. I mean, I could just go with that one is there a reason why I need any more ideas here.	
PST 4	You could 100% test this one and go with this one. But I would recommend making just one more - one more brainstorming idea. I know you want to stick with your first one, but I would make another one because honestly you never know with another variation in design –	(S) Multiple Ideas
	maybe changing up the shape, maybe change up the angle, a little bit - might just make that little bit of voltage output just much more … So I would just make you know another brainstorming idea, and maybe you might like that one better than the one that you just made.	(S) Support Idea 2

Note that we did not code PST 4's statements about changing the shape or the angle as offering variables given that they were not delivered as a suggestion but rather more so as examples of what PST 4 and Savannah had just discussed (see Table 8a). For the final three minutes of the discussion, PST 4 focused on encouraging Savannah to consider Idea 2 (supporting code, *Support Idea 2*), leaving it up to Savannah about how to alter Idea 1 to generate Idea 2 or to "create a whole different design" (Table 8c).

Table 8c. PST 4 Transcript Segment 3: Developing Idea 2

Speaker	Turn	Code
PST 4	So - Maybe pick maybe pick one or two things that change up with this design oh that's different from the first one.	(S) Support Idea 2
Savannah	Okay. Hmm.	
PST 4	So … what do you think you should, are you thinking to change?	(S) Support Idea 2
Savannah	Well -I don't know I mean I really like my square idea because we didn't test it like I told you before, but maybe this other shape the triangle, where the point was faced away from the hub that that was pretty good too. So I could, if you really think I should have a second design, I could make it with triangles instead but, but not the triangle that points to the hub - the one that points away, do you know what I mean?	
PST 4	Yeah, there you go, yeah. In picking another design like that - you know ... maybe change up another thing just because. You want a variation in your design. You know, so I'd maybe change, you know, what's another thing that, another thing that we could change, maybe?	(S) Support Idea 2

Speaker	Turn	Code
Savannah	I don't know, maybe I guess another thing that would be maybe easy to change could be the number of blades because I kinda like four blades. But I started that team tested three blades too and those - those are about the same so maybe - maybe I could do three blades that are triangles so that's something.	
PST 4	There you go. Change up the design and you still might like the first one, the first idea better. You know, you never know …	(S) Support Idea 2
Savannah	So … do you think I should write it as another idea on my brainstorming page.	
PST 4	Yes, I would just do number two and then a whole different design and then write down everything that you changed, and if you change even more things, maybe the angle, if you want to get crazy, I mean just you know it's another brainstorm ideas so it's whatever comes to your mind.	(S) Support Idea 2
Savannah	So I could change some of the other variables, too.	
PST 4	Yeah it's - You know you already changed the shape and the number of blades so I mean if you want, you can change the angle, you can change how far it is from the hub. It's up to you.	(S) Support Idea 2
Savannah	Yeah. So … I think I have some ideas that I'd be okay with … I really do still like my first design, but I … could add some other things …	

High Hindering PST12

We applied 15 codes to PST 12's transcript; 5 of those were supporting and 10 were hindering. Supporting codes included *Support Idea 1, Support Idea 2*, *Progress*, and *Multiple Ideas*. Hindering codes included *Evaluate Idea 1*, *Evaluate Idea 2*, *Offer Variables*, and *Offer Design Ideas*. PST 12 began the discussion with a supporting prompt about Savannah's first idea and then about Savannah's second idea – what it might be and if she had a second idea (Table 9a).

Table 9a. PST12 Transcript Segment 1: First Idea Support and Second Idea Inquiry

Speaker	Turn	Code
PST12	Hey, Savannah. How are you doing?	no code
Savannah	Oh, hi. How are you?	
PST12	I'm alright, I see you jotted down some ideas about your blades. Mind telling me a little bit about, well, what you got down there?	(S) Support Idea 1
Savannah	Oh yeah, I'm, I'm really excited about it. It's really, really cool. So this is my first idea and I really, really like it … I've got four blades … and I'm going to use a 15 degree angle and uhm yeah, I'm just excited …	
PST12	No, go ahead. Go ahead.	no code
Savannah	OK, so it's a … I was trying to be creative 'cause, it wasn't like … any other shapes that we tested out. So I wanted to try a square and so it's a square and it's 8 centimeters by 8 centimeters.	
PST12	Do you have any other ideas along with that or is that the only one that you're working on at the moment? Or do you plan on working on another one?	(S) Support Idea 2 (S) Progress

More hindering prompts emerged in the next segment for PST12, which started with Savannah's hope that she only needed one idea on her brainstorming page (Table 9b). These prompts

included offering design ideas, evaluating ideas, and the suggestion that both brainstormed ideas would be tested. She also used a supporting prompt in this segment with respect to the first idea.

Table 9b. PST12 Transcript Segment 2

Speaker	Turn	Code
Savannah	Well, I mean, I just thought that that was such a good idea. Like, I just figured I could stop there and just put the one down. I mean, is that OK? I mean, I - I just. I really like it.	
PST12	I mean, yeah. I mean one's, all right, but what if you - let's say instead of four [blades], what if you wanted to go by three [blades]? Do you think that would have impact the - the output voltage? Of the blades? Turbine?	(H) Offer Design Ideas
Savannah	I don't know. Maybe because, like when we did that test in our science investigation, it was like about the same almost between three and four blades. So I picked four 'cause I think 4 looks cool, especially when there are squares. But you know, I guess it could be 3.	
PST12	I mean, yeah, four does look cool too. I mean 3 - and 3 also looks cool, you know? And if you think about it, that's like 1 less blade you gotta worry about to make. You know, it'll save you some time as well. But OK, so that's awesome.	(H) Evaluate Idea 1 (H) Evaluate Idea 2
Savannah	Oh, oh, OK.	
PST12	Okay So yeah, we can go with three or four. Uhm, you know, it's better to have both ideas down, you know, just to be saying just, you know, it's better to test that because, you know, one could work better than the other. Or, who knows, like four might be better like your idea or but you know, you never know how the other idea might work out - what if you - I see, well, you have the measurements at a 8 by 8, um, centimeters. Can you tell me why you decided on the 8 by 8?	(S) Multiple Ideas (S) Support Idea 1

After Segment 2, Savannah explained her decision making about choosing an 8 cm by 8 cm square shape for her blade. What followed were several instances in which PST12's contributions to the discussion may have hindered Savannah's engagement in brainstorming. In Segment 3 (Table 9c), this took the form of evaluating the first idea and offering design variables and ideas.

Table 9c. PST12 Transcript Segment 3

Speaker	Turn	Code
PST12	I see. That makes sense. OK. And you know, like this, because it's just square. If you think about it - it's like it's so even on all sides. If you think about like the weight of it, it's kind of like evenly distributed everywhere. You know what I mean? It's like each side will have to same amount of weight. But what if we were, we were to maybe extend one side, what if we were to let's say increase the length maybe by another centimeter or two and maybe decrease the width? Do you think that would have an effect on the turbine?	(H) Evaluate Idea 1 (H) Offer Design Ideas
Savannah	I mean, I think it, I think it might. I mean we didn't do both of those things like at the same time in our science. We just saw that like it was better to have a shorter blade and it was better to have one that was a little bit wider. So I don't know, right?	

Speaker	Turn	Code
PST12	Right, right. I mean, we just don't know. That's why we can be able to like, you know, maybe - maybe consider or try other shapes that can also work. So like how you have four blades that are squares. Maybe you can have three blades that are let's say possibly we can keep that 8 by 8. But what if we cut - cut blades in half, but instead of like. If I'm going edge to Edge, we can cut them diagonally like draw big X on the on the square.	(H) Offer Variables (H) Offer Design Ideas
Savannah	Oh, like a triangle. Like it - is it?	
PST12	Right.	no code
Savannah	Is that what you're saying is make it make the square into a triangle?	
PST12	Right. No, I mean that's just one shape you can make or if you wanna just cut them in half, that will make 2 - 2 skinnier rectangles, you know? That could also work. Or you know what else do you think that you might be able to do to make some other shapes?	(H) Offer Variables (H) Offer Design Ideas
Savannah	I guess I could make different triangles, but I remember in the science investigation like one kind of triangle didn't work as well as the other and the rectangle wasn't maybe so good. So I'll have to look at like, what if I change this shape like what it'll be like we don't know about a square, but we might know about one kind of the triangles maybe?	

The final part of PST12's discussion with Savannah, not shown here, included praise for the second idea that Savannah began to develop: "It looks awesome!" We coded this as hindering, *Evaluate Idea 2*.

Discussion and Conclusion

These findings suggest that PSTs, with only minimal experience with brainstorming themselves, are likely to come to engineering education learning experiences with ideas for productive prompts to support brainstorming. All 18 participants used supporting prompts which we coded as: *Support Idea 1*, *Support Idea 2*, *Science*, *Brainstorming*, *Progress*, *Multiple Ideas*, and *Creative*. Collectively, these prompts encouraged Savannah to share her idea thus far, generate a second idea, draw from the relevant science, share how brainstorm is going for her, explain why she has just one idea thus far, assert the importance of having multiple ideas during brainstorming, and encourage Savannah's creativity. These are consistent with ideas in the literature to support divergent thinking—most especially, to conceive of as many ideas as possible [2], to provide a reason for why it is important to brainstorm multiple ideas [1], and to be creative, generating unusual or wild ideas [7].

That said, and as shown in Table 4, there is room for PSTs to learn to use more and a wider range of supporting prompts. Less than half of participants used supporting prompts that we coded as *Brainstorming*, *Creative*, or *Science*. Even High Supporting PST 4 did not employ prompts to specifically ask about how the process of brainstorming—using the word to signal this part of the design process—was going to encourage Savannah to be creative. These low frequency supporting prompts represent learning opportunities for PSTs and areas of focus for engineering teacher educators [6, 8]. Also, encouragement to offer wild or playful ideas was largely absent from the transcripts [7]. This may be due to the significant constraints on the challenge and the focus on applying scientific ideas in the science-integrated design challenge.

All PSTs used hindering prompts. Those were *Evaluate Idea 1*, *Evaluate Idea 2*, *Offer Variables*, and *Offer Design Ideas*. The first two are consistent with the broader idea critique should be paused while ideas are being generated [2]. While this advice is generally towards those doing the brainstorming, in the classroom setting, this includes the teacher as well; any evaluation, including praise, can stifle idea generation. Nearly all the turns coded as *Evaluate Idea 1* or *Evaluate Idea 2* were instances of praise, the intent of which was likely to be encouraging. This leads us to consider ways that we can suggest to PSTs that they can praise the brainstorming process rather than the quality of the ideas generated during that process. For example, PSTs can be encouraged to praise Savannah for getting started on the brainstorming process by having one idea, generating a second idea, or being willing to use her creativity to generate more ideas.

The latter two hindering prompt codes identified instances in which the PSTs offered (a) variables Savannah could or should modify to generate Idea 2; and (b) specific ideas Savannah could or should consider using. The difference between the two is the level of specificity, e.g., the idea to change the number of blades (*Offer Variables*) versus the idea to have three blades (*Offer Design Ideas*). The more hindering of these two is the latter, which is like offering examples during brainstorming—a practice to be avoided [7], and one that is evident in the transcript excerpts from PST 12. The former, *Offer Variables*, may also be hindering in that it may prevent Savannah from deciding on which of the variables she may be willing to change to generate a second idea. PST 4 provides an example of what this might look like in PST 4's multiple queries that took the form of: "What is one thing that you might consider changing?"

Relatedly, after coding the data, we realized that the large percentage of hindering moves that we coded as *Offer Variables* may be due to suggestions in the simulation scenario (see Appendix). Those were suggestions, seen by all PSTs, about questions to encourage Savannah to consider other ideas and included three questions: (1) Are there any other numbers of blades that you might consider? (2) What other blade shapes could you try that might distribute the mass differently? and (3) Would you consider any other blade dimensions? These were provided with an intent to be helpful but were themselves potentially hindering as they did not suggest asking Savannah what variables she might be willing to consider changing in a broad way. Thus, one outcome of this study is the editing of the simulation scenario to remove these suggestions.

Reflecting on the study, we also recognize that while all children should be given the opportunity to generate their own ideas—which we see as a form of encouraging their agency and sensemaking—there are some children who may need more direct suggestions. This is an area that needs additional attention. In the absence of research in this area, our suggestion is to start with broad suggestions (e.g., What variables could you change?) and if those lead to significant struggle or challenge students' needed accommodations, offer more specific suggestions (e.g., How about considering a new shape? What other shape could work well?).

Finally, we see the transcripts from this study as being useful teaching tools for future cohorts of PSTs in engineering education coursework [27]. These transcripts can be used for PSTs to find examples of supporting and hindering prompts, to consider alternative ways to encourage Savannah to generate a second idea, to compare different approaches used to support brainstorming, and to discuss brainstorming and multiple idea generation as an important part of engineering design.

More work is needed to explore how PSTs and teachers support brainstorming and how students engage in it [6]. Our own future work on this topic investigates how the PSTs in the second and third years of the study connected their experience with Savannah to their experience in a field placement teaching engineering to real middle school students. This exploratory work examines how PSTs' engagement in simulated learning experiences like Savannah's Idea Fixation scenario may translate into real teaching environments. Additionally, we are curious about how PSTs might respond to students with personas different than Savannah who have trouble with brainstorming or are experiencing idea fixation.

Acknowledgments

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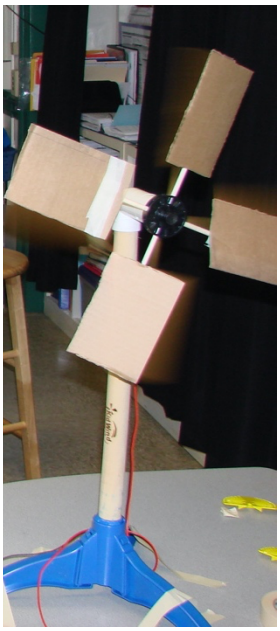
Appendix

Savannah's Idea Fixation Scenario

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

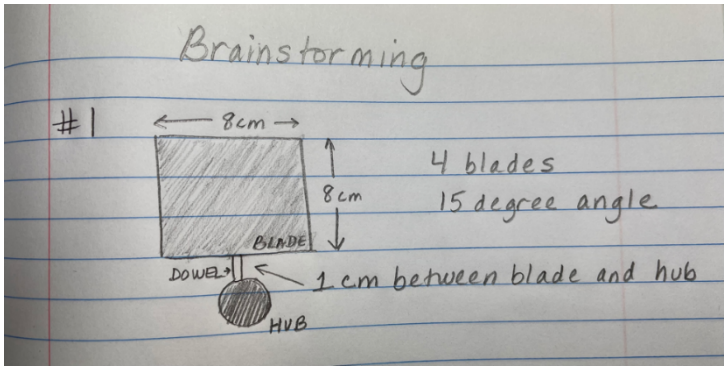
Note: All blades were rectangular except when examining mass distribution.

[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.

Idea Fixation during Brainstorming. After exploring these variables and before placing students in their engineering teams, you asked each student in the class to independently brainstorm at least two possible blade systems that would maximize output voltage. You suggested to the students that they consider the variables that they explored in their scientific investigations. You also reminded them that not every possible condition was studied (for example, we don't know about angles less than 15° since those were not tested). You asked students to sketch and label these brainstormed ideas in their engineering notebooks. As you monitored students during this 15-minute brainstorming session, you noticed that Savannah and a few others had only sketched one idea on the "brainstorming" page of their notebooks. She may be fixated on this one idea (i.e., experiencing idea fixation).

About Savannah. Savannah is a good student. She has an excellent memory, has strong analytical abilities, and is an introvert. A perfectionist, Savannah responds best in learning environments where she knows specifically how to succeed. She is very good at figuring out the one right answer that is often expected of her in her classes. Engineering design challenges are a bit stressful to Savannah in that they feel open-ended without clear directions for success. (Image and elements of Savannah's description are from Mursion®.)

Savannah's Brainstormed Idea. This image is what you see when you look at Savannah's brainstorming page of her engineering notebook. Some questions that you might use as you encourage Savannah to consider other ideas (without evaluating her ideas or telling her what ideas she should use) are:



- Are there any other numbers of blades that you might consider?
- What other blade shapes could you try that might distribute the mass differently?
- Would you consider any other blade dimensions?

Note that this is not an exhaustive list! There are other questions you might ask. Think about what those questions might be in order to meet the goals of the discussion, described below.

Your One-on-One Discussion with Savannah

You decide to talk with Savannah one-on-one. Your goals in this short discussion are to:

(1) Get her attention when you first get onto Zoom (she'll be writing in her notebook);
(2) Elicit ideas about Savannah's first brainstormed idea;
(3) Support Savannah to add at least one new idea for a wind turbine blade system to her brainstorming page (i.e., she has Idea #1 already; you want to support her in adding at least one more idea, Idea #2, that is different from Idea #1); and
(4) End your discussion before 9 minutes have elapsed (recommendation: use a timer!).

Note that your goal is ***not*** to critically analyze her first idea!