Open-ended Modeling Problems and Engineering Identity

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Abstract

Engineering identity is an integral determinant of academic success in engineering school, as it allows students to have an understanding of themselves in relation to what they study. Studies in engineering and other STEM disciplines have shown a positive correlation between identity and retention. Previous studies by Carlone and Johnson, Hazari, and Godwin have examined the following facets of a STEM or engineering identity: performance, competence, recognition and interest. While many current papers examine how culture and social interactions may influence identity, this paper examines how doing engineering coursework can uncover or influence a student's engineering identity.

This comparative case study examines how two students' experiences solving an Open-ended Modeling Problem (OEMP) in their statics class may have contributed to their engineering identities. Cristina and Dylan, our two cases, both recalled how they solved a problem about a hands-free crutch device in an interview at the end of the semester. None of the questions were explicitly about identity. The interviews indicate that both students were interested in solving these problems and recognized themselves as being capable of solving the problem. In the case of Cristina, the problem helped her build confidence, both through her understanding of the material and her problem solving abilities. Our results also saw both students discussing how the disciplinary authenticity made them 'feel like an engineer.'

Implications of this work include a deeper understanding of how day-to-day problem solving within courses can influence engineering identity and may aid in understanding how certain activities and scaffolding can influence engineering identity. This is important as students who have strong engineering identities are more likely to stay in engineering, become competent engineers, and find success in their respective fields. This research can inform educators on the importance of assigning novel, ill-defined problems that require students to apply their critical thinking skills and logic skills in real world situations.

Introduction

In the last few decades, research on engineering identity has substantially increased. In fact, at ASEE last year, there were two sessions in the Educational and Research Methods division focused explicitly on engineering identity. Much of the recent work on this topic has been spurred on by Godwin's instrument [1] to measure engineering identity. While the factors of this instrument are built on previous qualitative studies (detailed in the background below), many studies have used this quantitative measure. In fact, in those identity sessions at ASEE this past year, three papers used the instrument [2]–[4] and one used the identity framework [5] from Godwin's work.

Recent systematic literature reviews, published in 2017 [6] and 2018 [7] give us an indication of the areas of focus within the field. Most studies highlight the need to pay attention to the formation of engineering identity to retain students and aid them in persisting in engineering, particularly women and students from minoritized racial/ethnic groups [6], [7]. Rodriguez [7] reports that 25% of reviewed articles focus on women and gender and 25% focus on underrepresented racial and ethnic minorities. Studies examining engineering identity start as early as K-12 and extend through undergraduate and graduate experiences to those of practicing engineers [6], [8]. Many studies, especially at the pre-college levels, focus on exposure to engineering activities [6]. At the undergraduate level, some examine exposure to content while others discuss how working with peers or on teams, typically in design experiences, shapes one's engineering identity [6], [9], [10]. Studies have tended to focus on engineering identity related to engineering design contexts and identity in the first and final years of engineering study; in this work, we focus on engineering identity as it relates to engineering science in the core engineering science courses that students take. Specifically, we look at how a contextualized problem solving experience may contribute to developing engineering identity.

In this paper, we examine interviews with students about a novel, real world, complex, ill-defined problem assigned in their Statics course. Previously, we saw these students had generally positive experiences solving this problem [11]. In our reading of the transcripts for other analyses, we saw students described how solving this problem felt like "the most engineering thing we have done this year" and made them "feel like an engineer." These and similar statements provoked our curiosity about relationships among students' experiences with open-ended engineering problems and their engineering identity. Therefore, this paper looks at the influence of solving such a problem on students' identity, asking:

RQ1: How does an open-ended, real-world problem influence the development of student engineering identity?
RQ2: How do open-ended, real-world problems generate a sense of engineering identity?

Background

The engineering education community has recently shown high interest in the study of engineering identity development in undergraduate students, which has been found to have important links to student retention and education, perhaps particularly for students from populations underrepresented in engineering [6], [7], [10]. Godwin's work on the development of a survey instrument to measure engineering identity [1] has been widely cited and used within the field in recent work. Godwin's instrument employs a three-factor identity framework that includes interest, recognition, and performance/competence grouped into a third facet. Godwin defines recognition as the "feeling that others see them as a good engineering student," interest as the "desire/ curiosity to think about and do well in engineering" and performance/competence as the students' "belief in ability to perform required engineering tasks and understand engineering content" (p. 4) [3].

Godwin's model of engineering identity builds on research into students' identity in relation to science and mathematics, which has taken place over the course of two decades. Researchers such as Gee [12] have been forming comprehensive ways to map identity in relation to education since the year 2000. Gee was one of the first people to map a person's identity in relation to their education. In 2007, Carlone and Johnson [13] began to build off of the idea of identity in relation to science education. Their study on the identities of women of color in science produced a framework that included three elements of identity: performance, recognition, and competence. Carlone and Johnson defined performance as "social performances of relevant scientific practices- e.g., ways of talking and using tools," recognition as "recognizing oneself and getting recognized by others as a 'science person,'" and competence as "knowledge and understanding of science content" [13]. We draw on Carlone's and Johnson's work in undergraduate science identity to inform our study of undergraduate engineering identity. Hazari [11], in research focusing on physics education, expanded on Carlone's and Johnson's identity framework by adding a fourth factor: interest. Hazari defined the factor of interest as the desire/curiosity to think about and understand physics. Hazari also changed the definitions of recognition to "recognition by others as being a good physics student," performance to "belief in ability to perform required physics tasks" and competence to "belief in ability to understand physics content" [14] (p. 982). By adding the fourth factor of interest, Hazari was able to show that interest in the subject of science influences a student's persistence in science. Godwin, in turn, adapted Hazari's framework into the three-factor model (interest, recognition, and performance/competence) used widely in current engineering education research.

In order to explore the relationship between the development of engineering identity and students' completion of open-ended modeling problems (OEMPs), we draw on this body of STEM identity literature. As we began to apply qualitative analysis of engineering identity to interview transcripts, we felt the need to return to Hazari's categorization of performance and competence as separate factors of identity. In this work, we therefore consider the factors of engineering identity to be performance, competence, interest, and recognition. *Performance* is the ability to complete a problem, i.e. the outcome of hard work. *Competence* is the ability to exhibit understanding of a problem through use of applicable knowledge and critical thinking skills. *Interest* is the student's desire or curiosity to learn about engineering: an example of this is when a student goes above and beyond to gather understanding on the topic. Finally, *recognition* is separated into three subfacets, which reflect the deep work done by Carlone and Johnson on recognition in science identity: lack of recognition, social/teacher recognition, and self-recognition. While Hazari's work touched on the idea of self recognition, the focus on areas other than recognition by others have not received as much attention as the identity model has been adapted into engineering. In this work, we seek to renew attention to performance, competence, and interest in engineering.

Methods

The authors are all women in engineering who have been in spaces where we are in the minority. At times, some of us have struggled with our own feelings of lack of competence or belonging in the discipline.

Participants

Maroon University is a small, private university in the southwestern United States. Participants in this study were students from Maroon University who completed a Statics course during the second semester of their first year at their university. In addition to assignments from the textbook, students in the course were asked to solve an open-ended question about a real device, the iWalk 2.0 Hands Free crutch. This question was assigned as a three-part project: an individual homework assignment in which students had to make initial assumptions about external forces, a second individual homework where students were asked to perform frame analysis and solve for or choose a radius and material for one member, and a third group part in which students were asked to compare all their models and extend the analysis in some way (e.g., consider another stance or perform the analysis for walking on a slope). Each assignment did not have a single, correct answer and students were tasked with solving the problem using concepts learned in class, materials given by the professor, and personal research. More details about the problem creation [15], how students responded to the problem [16], and the emotions they experienced while solving the problem [11] are available in other publications by our research team.

In this study, we examine transcripts of interviews with two participants: Dylan and Cristina. Cristina is a hispanic woman, and Dylan is a white male. We chose these two participants as, from our previous analysis of these transcripts, the two students were about equally engaged in the problem. We knew going into the case study that these two students hold differing socio-cultural identities and were curious if those differences extended into the identity development that may have happened while solving this problem. We limited this study's data set to only two students after our first attempt at a thematic analysis across all interviews in the complete data set did not have clear findings, informing our decision to examine each student as a case.

Data Collection

These students were invited to participate in a Institutional Review Board-approved study about engineering judgment in which they could choose to participate in an interview, have their ungraded work reviewed by the research team, and/or participate anonymously in a survey. Students were also asked to choose a pseudonym. Students who consented to participate in interviews were randomly selected and sent an e-mail asking to set up a date and time. The interview took place on and was recorded by Zoom. During the interview, students were asked to recall how they approached solving the problem both individually and as a group, asked to evaluate their final mathematical model, reflect on their experience with the novel problem, and provide demographic information. The purpose of the interview was to understand students' thinking as they were problem solving, thus a semi-structured approach was used to discuss key decision points during the problem. The interviews were not originally designed to probe students' engineering identity; however, in the interviews, students made statements about identity, which prompted the analysis described below. Interviews were transcribed by undergraduate student assistants or an online transcription service.

Data Analysis

The authors used a case study methodology [17] including techniques from discourse analysis, constant comparative method, and memoing to define and understand the facets of engineering identity. Originally, the research team attempted a thematic analysis of the interviews, but that method was rejected as it did not provide a clear picture of each students' identity. The second author read the two transcripts individually, making notations on utterances relating to factors of identity (competence, interest, performance, and recognition) as described by Godwin [1], Hazari [14], and Carlon and Johnson [13]. The author then created a memo making arguments about identified utterances to build a case study of each participant. She presented her analysis to the other authors, discussing her arguments with the first author and then the larger research team in which the arguments were debated, iterated on, and finally all agreed upon. . She then wrote up both cases and received feedback from the other authors who iterated on the comparative case study. All four authors reviewed and agreed on the quotations selected and the comparative cases presented.

Findings

We present our analysis in the form of a comparative case study examining how two students from the same course at the same university, Cristina and Dylan (student-selected pseudonyms), experienced the open-ended problem, and we examine how completing a novel, open-ended problem may have influenced their engineering identity.

Cristina

Throughout her interview, Cristina gives us a good idea of her engineering identity through comments made when explaining her method of solving complex problems. Throughout the transcript, we found indicators of competence, performance, interest, recognition, self-recognition as well as negative recognition. It is important to look at all of these identity facets when beginning to understand Cristina's engineering identity.

Interest

Cristina is interested in engineering and the work she produces in open-ended problems much like the iWalk. When asked to explain the way she solved the first individual part, Cristina explains that at first she was pacing her room trying to figure out the best steps to take for the problem. She ends her explanation of her process with the sentence below:

> Cristina [00:07:35.15] "at first, right, I wasn't used to this kind of problem. But like, um, I know like I found myself like walking back and forth in my dorm like trying to figure out, you know, choose a stance and then […] the [stance] I chose I just felt like put the most weight on like that one member AB. [...] So at first I wasn't really sure - like I was kind of like, I avoided the problem until I actually had to do it because I was just like unsure of it. But then once I actually got to doing it, **I kind of liked it because it's like, you can make the call on things**.

Due to the open-endedness of the problem Cristina is able to find joy in solving the problem. She expresses that she enjoys being able to make the call on problems (interest).

Performance and competence

When asked to explain why she thought her model was best, she was able to explain in depth why she believed her model to be accurately made (competence); additionally, in her reflection on her work, she demonstrates a thorough understanding of the way she modeled the iWalk (performance).

> [00:36:47.29] Cristina: So best model? Oh, okay. So, like, as opposed to other stances. I just felt like this one mid-stance put the most weight on it and like, even after I was like looking at other people's like, um...because I got to look at my group members' like other models. And like I just thought, **mine was just the best like just because like that put the most force on that one member but also like...I just felt like it modeled it the best because, right, I took account of like everything** - I don't know … So I just felt like this one was the most direct force, on AB itself so like, that's why I felt like it was the best model to choose? Or like the best stance. And like as for like my report, I just feel like it was kind of thorough on like which members had the forces going in its own like directions and stuff.

Not only is Cristina interested in the work that is associated with the open-ended modeling problem she was also able to perform well on the tasks assigned throughout. By presenting her work in a thorough manner that is easily comprehensible and backed by logic, Cristina is able to score well on the project (performance): “Um, yeah, for the individual. I think I got, I don't know, like point wise it was close to 100,” and on the final report her group “did pretty well.”

Cristina is also asked how the problem makes her feel. She is able to express to the interviewer the feelings she was having through each stage of the problem.

> [00:58:20.02] Interviewer: Great. How did this problem make you feel?
> [00:58:25.28] Cristina: So typically, I'm not like very or like I said, I don't make decisions very quickly, or I'm like not very big on making decisions. And so, like, it made me uncomfortable because of that and like also like I wasn't sure of like being able to do it like on my own. Because like for like other problems sets you can go and ask your friends like to do ... like you do it together. And I like to do that like study together. Like this one, like I had to. It was my own like I couldn't just ask them, like, oh, how'd you decide to do it, like I could, but it was just like, I still had to do my own. So like, I say, like, overall, I was very uncomfortable at first, but then once I started getting into it and like doing like research about like the dimensions ... because like the whole free body diagram. Like that was like the starting point to like everything, you know, finding the dimensions and just everything. Then I thought it was like being like it was okay. Because, like, **then you can just solve it like normally but I just felt really like not empowered. Right. But, like, just like it was cool because I could like figure things out and then solve it like a normal problem**. And like, then just incorporate everything.

Cristina was able to indicate that she was very uncomfortable and uncertain of herself at the beginning of the problem. However throughout the course of completing the problem she was able to gain more assurance through her work and by the end she said she felt more confident (competence, and perhaps some self-recognition). Cristina seems to benefit from the integration of open-ended modeling problems into her school curriculum as it changes her engineering identity in a positive way.

Recognition
Cristina has a conflict between her developing self-recognition and negative recognition that she receives from her groupmates. Cristina mentions that she is soft-spoken in group settings, stating “I'm not really like when it comes to groups. I'm kind of just like a little bit more like, I don't know. Don't speak as much of my voice as I should.”

Cristina’s reporting of group interactions and how her group members respond to her shows she is met with some pushback to her problem solving methods and judgment when put into a group setting. Cristina recalls in the interview one or some of her group members questioning her methods of solving problems but reflected that is how it made sense to her:

> [00:14:49.29] Cristina: So like [making tables to track forces] made more sense to me. So I just made it separately but I know like **when I showed my group members** for the

> other one like my table **they were like why did you make so many tables**? And I just felt like it made more sense so it was kind of more organized myself.

Similarly, she reports her teammates questioning why she made a particular assumption, the stance she chose, criticizing the choice because it was easier to model (negative recognition). Cristina is able to go on to explain in the following quote that she believes it is the best stance because she is able to understand it as well as provide mathematical proof to back up her choice (competence). She is even able to go further to explain that she finds this process 'cool' because she is able to provide justification to her design decisions (interest). However, she faces slight pushback from her peers, when she is told that she chose her stance due to it being the 'easiest' choice (negative recognition).

> [00:09:38.09] Cristina: …I remember **someone had made like a comment that I chose the "easiest" stance**. (she used air quotes when she said easiest) And I don't know. I was just like, I don't, like it's simple, but I honestly thought like, this is the one that put the most weight on that one member that we were looking at so I was like, **I don't think it's just simplest I just like, that's actually what I think. Put the most [axial load on the member].** And then like it was cool, because I get to justify and like you know, put - do the numbers on it.

Prior to the quote above, the interviewer had mentioned that Cristina's group had good free-body diagrams of the device. Cristina mentions then that she wanted to do a rectangular load distribution but was vetoed by the group. It is shown that Cristina recognizes her own potential, but is resistant to speaking up and advocating for implementing her ideas from the individual portion of the project into the group project. She returned to this idea later in the interview:

> [00:52:01.11] Personally, like **I felt like the way we distributed the triangle thing wasn't ... like that wasn't really mine**. Right, so I that wasn't as accurate as it could have been, but like everything else... I feel like, oh yeah, also something else like where they placed like the force normal was different than my original individual like because we placed the force normal like um not in the middle of AB. I don't know**. That ... that kind of had me like not sure but you know, I feel like that makes ... doesn't really affect it a lot. But still, like, that was different than mine** [...]

In contrast to those experiences, when talking about how the class and the project forces you to have comprehension of the topic and subject matter applied that is applied to the questions asked she states shortly after:

> [01:03:24.23] Cristina: And so, I kind of like that because then it's like, then you're, you think about it more as you're doing like the other things and the other projects like you think about that, **you can like um not ... what's the word... like to reassure yourself with your knowledge of calculations** and things like that

Cristina is able to find assurances with her own knowledge (self-recognition), this indicates that through the completion of the problem she is able to have further understanding of the topic and have more confidence in her own work (competence). This is a significant change from the previous bouts of uncertainty in her work that she expressed having earlier in the interview. After completing the open-ended model problem she is asked if she would assign a problem like this if she were to ever teach this class.

> [01:05:33.22] Cristina: I think I would, because I like you, like, especially after doing it like they just learn a lot from it and it's just like **you get confidence, kind of in yourself and like the way you teach or the way you like the way you apply like all the concepts that you've learned**. It was kind of like a final test. I think it is. But yeah, I think it's worth giving out.

Cristina indicated that because she found the problem so thought-provoking and beneficial to her schooling on a personal level that she would assign an open-ended modeling problem if she were given the chance to in the future. She mentions that through completing the open-ended modeling problem she was able to gain a level of confidence going forward in her work, reflecting both her self-recognition and her competence despite the fact that she had some negative effects with respect to recognition from her team.

Dylan

Similar to Cristina, Dylan made a variety of comments that give us clues about his engineering identity in relation to the OEMP. We found evidence of interest, conflicting evidence between his performance and competence, and some evidence of self-recognition.

Interest

Dylan shows interest for the work that he is producing through the open-ended modeling problem. He is asked to compare the task at hand to his vision of an ideal engineering task. He goes on to explain how he feels about the classical learning methods through things like slideshows and exams, and says that in comparison to an open-ended problem he finds this a lot more interesting and engaging: “It's going to be more similar to this project. And so I enjoy this.”

Dylan’s idea of what an engineer should be doing is communicated through the use of the word “creativity” during the interview. Dylan talks about creativity to communicate that thinking out of the box is a skill that is going to be useful when he is in industry. He expresses his thoughts on this idea when asked if he would assign an open-ended modeling problem if he were to teach mechanics one in ten years he responds with:

> [01:13:00.01] Dylan: Absolutely. I guess I don't know what it means to be an engineer yet. I just took Statics, but **I would hope that you would need to be good at this type of thinking.** And I feel like if you go out, you get your degree only with direct learning -- however you want to word it -- that we have in most of our classes that you wouldn't be at the level that you could have been at and I feel like **problems like this allow free thinkers to make more of a of a show in classes**, instead of just look smart. There's a place for both, but I just - I like how **creativity can earn credit where credit's due**.

When asked by the interviewer to explain his meaning of creativity Dylan gives examples of things his group has done:

[01:15:03.22] Dylan: Well, for example the other member of my group, the one that used the pixel method [to estimate distances], that was a creative solution to a problem presented. And I feel like if we were just given the crutch as a problem we needed to solve, and it asked us, and they gave us dimensions, then we'd never have the opportunity to explore ways to find those dimensions. And so the creativity in the ways to come up with those dimensions I feel like is this important tool that will be needed in real world scenarios. Because in real scenarios, obviously you're not going to be given everything you know and you're going to need to make assumptions. So that's kind of what I meant by creative.

Dylan finds interest in the open-ended modeling problems not because it furthers his ability to complete engineering tasks but because it allows him to think in non-traditional ways, calling back to his attraction to creativity and free thinking.

Dylan, overall, is very interested in the way people solve problems and the way problems can be looked at in multiple different ways. When asked, he explains the reason his model is an acceptable approximation to reality by saying:

[01:00:44.20] Dylan: "But **whenever there's more people doing the math. You can see the different ways they went about it.** And whenever you see two people approaching one joint a different way. Then you realize that since there's two methods to solve it this way. There's also two different ways it can be looked at. If there's two different ways it could be looked at then one of those is probably going to be better than the other. And so by individuals talking about each way that we solved it different, we were able to come to a conclusion on which was more appropriate for the model. And I think that was what made it better in the long run."

Performance and Competence
Dylan received validation that he produced a good model of the iWalk device (performance) by comparing his calculated diameter to the actual diameter ("it came close to my three centimeter estimation on my own") and the grade he received for his work ("We made an A. I think it was a 95"). Overall, Dylan's work on the iWalk problem validated his ability to complete and understand complex engineering tasks.

However, Dylan experiences some conflict between his performance and competence.

[00:27:40.26] Interviewer: Tell me why the way you modeled this problem is complete enough.
[00:27:53.24] Dylan: Am I allowed to say **I don't think it is**?
[00:27:58.12] Interviewer: Yeah, you're allowed to say that. Why would you say that?
[00:28:04.10] Dylan: I feel like I would've needed to put in a lot more time. Honestly, my honest answer is I feel like I would have had to put in a lot more time than was necessary for the homework assignment in the middle of a semester. Um, I feel like I met all the criteria that was given to me and did my best to lay out assumptions and stuff but I just feel like **my assumptions were not nearly accurate enough to be used as an actual**

> **dimension for an actual product**. And, so I feel like if I had more time, I could've better made my assumptions better and I feel like I would've needed time to do physical testing based on my assumptions. And, as far as just laying it out on paper, I feel like I did a decent job of modeling and laying out process but **I don't think my assumptions are anywhere near accurate**

Dylan demonstrated that although he completed the assignment to the best of his ability, there are more steps he could take to create a better model (competence).

We also see evidence of competence in his ability to see the limitations of the model he is building in only analyzing one stance and not the whole gait. In a follow-up response that asked him what he would to to make the model better, he replied:

> [00:29:28.07] …the design for one stance left out error for uh…just because I determined an actual stress whenever the force was straight down (analyzing his choice of mid-stance) and the weight of the person doesn't mean that when the person starts to move, there's no bend in the material in my eyes. And so, I feel **it would need to be analyzed at each position to make a more accurate assumption.**

Dylan's analysis of the accuracy of the model he was given shows he has an understanding beyond just answering the question in the assignment.

> [01:13:59.17] Interviewer: What about the group project? Would you assign the group project if you were teaching the class?
> [01:14:06.29] Dylan: Yes, because I really think being able to collaborate with other people and see their ideas ... because originally coming out of the original assignment I had thought I had done a really good job. But now going back and looking at the difference between the two and seeing how much we actually changed in the group project and how much better it is. It makes me realize that my individual one isn't perfect at all and that there's so many things to change that I didn't think of it all. And so **being able to work with the group really shows you that there's so many different ways to think and one person alone can't think in all those different ways a lot of times.**

Recognition
Dylan's confidence is something that is shown in many situations where he is working with his peers, when he is asked how the problem makes him feel Dylan says:

> [01:04:37.14] Dylan: Before I met with my group, It made me feel fairly smart in a way that I was proud that I had come up with a lot of the assumptions I came up with. I had never really done an open-ended project like this and everything was always given. And so whenever I first sat down and looked at it, there was a while where I was like "I don't know where to start." And by the time I had laid out all my assumptions and I was able to go through and then the math, which is supposed to be the more difficult part actually seemed easy because of all the work I'd put into accurately laying out assumptions **and I was just proud ... I was happy with my work on the assumptions. I was proud that I was able to come up with my own design limits.** If that makes sense.

Multiple facets of engineering identity such as self-recognition and performance are shown through Dylan's recount of his processes. Self-recognition is shown when he says that he was proud of his work and how he felt smart even before working with his group members. His ability to perform was shown when he said that he had accurately made his assumptions which then allowed him to have an easier time completing the problem.

Discussion

To compare Dylan's and Cristina's experiences, we examine the evidence that we found in the order that it occurred for the students. Both Dylan and Cristina expressed that they were initially unsure where to start on the individual assignments, though this seems to have been more pronounced for Cristina, who spent more time explaining her discomfort working on a problem without friends the way she would do for typical homework problems. However, this discomfort led her to do a huge amount of research before tackling the free-body diagram. After the individual portion of the assignment, Dylan felt confident because his calculations felt easy after making the assumptions, and the open-ended format allowed him to showcase creativity, which he considered to be an important aspect of engineering. Cristina enjoyed it once she was able to complete the free-body diagram and see how she could solve it (almost "empowered"), and felt that choosing the stance ("making the call") was enjoyable.

Once they got into the group assignment, we saw a larger gap between their experiences. Dylan's experience in the group largely built his interest and confidence, since he enjoyed seeing how different individuals had approached the problem and he felt the final model was an improvement on his individual solution. Cristina's group experience was much more mixed: she received negative recognition from group members about some of her modeling and organizational decisions. All the work she had done during the individual portions of the assignment gave her confidence that her decisions were actually better than some of the ones the group made, affirming her competence, but her difficulty speaking up in the group setting meant that those choices did not make it into the group's final model. We note that Cristina's use of the word "voice" in describing this difficulty is significant in its connection to Belenky et al.'s foundational work on women's learning [18], in which the development of a voice (i.e., comfort speaking up and sharing thoughts or ideas) is associated with intellectual development.

Finally, we have evidence from the students' reflections on their experiences overall. In Cristina's interview, she concluded that she would assign OEMPs if she were teaching Statics because "you get confidence" in yourself. Despite experiences of negative recognition, she even said that she would assign a group portion:

> [01:06:19.20] I think I would. Only because like everyone gets to see how everyone else thinks about it like you it kinda opens ... you're happy about it. [...] And like I liked how we put it together in like an official report. I like that because then you get to reflect even more about it. Overall I think yes, because like you get to see everybody else's opinions and like their thoughts and how they go through and things like that.

Particularly important to her reflection at the end of the interview was her observation that she could reassure herself with her knowledge of calculations in future design projects, indicating she feels competent. Dylan also concluded that he would assign an OEMP if he were teaching Statics, but for a different reason: he hoped that "this type of thinking" is something that engineers need to do after they graduate, and felt that the freedom in this project allowed him to demonstrate creativity. He concurred with Cristina that he would also include a group project, since "one person alone can't think in all those different ways." His experience reflecting on his individual and group submissions actually led him to see "how much better" the group's model was.

Examining Dylan's identity, we argue that the OEMP reflected and reinforced Dylan's image of himself as a future engineer but did not develop his identity further. Dylan uses the word *creativity* to express his idea of what an engineer should be and through this problem he is able to express what he believes is his free-thinking self. The idea that Dylan is able to express his competence, performance, recognition, and interest through his free-thinking mentality is further proof that Dylan already sees himself as an engineer or future engineer. Overall, Dylan was confident in his ability to do engineering work (self-recognition, performance) to complete the OEMP saying "Before I met with my group, it made me feel fairly smart in a way that I was proud that I had come up with a lot of the assumptions." However, he also acknowledged a gap between 1. his performance on the assignment and recognition from his instructor through a good grade and 2. what would be required in a real engineering scenario; his comments convey that he felt competent to be able to undertake that additional analysis, regardless.

In contrast, we argue Cristina gained a greater sense of identifying as an engineer through completing the OEMP. Despite Cristina's initial feelings of being "unsure" on how to solve an open-ended problem, she conducted a lot of research and carefully thought through the decisions to make her model. Despite being confronted by some criticism from her group (lack of recognition), the research and careful thinking ("took account of like everything") she did gave her confidence (self-recognition and performance) in her model and answers. While Cristina reported this group feedback to the interviewer, it didn't seem to change her own belief that she did a good job (competence). When prompted by the interviewer to argue why she had the best model, Cristina argued for why her modeling decisions were "thorough" and why her choices made her model the best. The process of going from unsure to completing the project allowed Cristina to feel "empowered" and "proud" and built up her competence and ability to do an engineering task (performance). Her ability to do engineering actions, and do them well, helped her recognize that she is an engineer, despite some groupmates not contributing to those sentiments. Cristina even seemed to explicitly tell us why a task like this is so important to assign when she expressed "you get confidence" from solving this problem.

Conclusions and Implications

Our approach to utilize the most current engineering identity model [1] to code interview responses caused us to return to the roots of the model [13], [14] to use it qualitatively. We separated competence and performance, finding one was more about a students' understanding of the concepts and the other about being able to complete tasks. Many times, though, we did find students' reflections including both ideas together. As students were discussing themselves in the interview and not the perspectives of others, we were able to find more evidence of Carlone and Johnson's self-recognition than how students were recognized by their peers, parents, and instructors. As these modifications were useful to the context of our data, we encourage other researchers using Godwin's model to use these building blocks of the model if needed.

This study focused on how one novel, open-ended problem contributed to development or reinforcement of students' engineering identities. This was an unintended positive result from assigning these problems that we find encouraging. While a considerable amount of literature on identity focuses on engineering culture or belonging, we see the benefit of some of this work may occur through the doing of engineering work as well. We posit that the agency [19] or choice [20] students were given to go about how they solved these problems may have contributed to aspects of identity building. Similarly, the real-world context and complexity may have contributed to a feeling of authentic disciplinary practice [19] or a stronger connection between students' day-to-day life and their engineering coursework. As this comparative case study is limited, we cannot draw any significant conclusions but see potential in assigning similar problems.

One key finding was assigning these problems in multiple parts, which allow students to iterate on their work, giving them more time to grapple with course concepts (competence) and complete the assignment to the best of their ability (performance). For Cristina, having built confidence in her competence and performance during the individual assignments before the group portion may have prevented the negative recognition from her groupmates from affecting as much as it might have otherwise done. We encourage other faculty to assign similar real-world, complex problems, especially in technical core courses when complex problem solving or design problems are not typically assigned. Not only does this aid in developing engineers who can solve complex problems [21], we also see here it may contribute to building their identity.

References

[1] A. Godwin, "The Development of a Measure of Engineering Identity," in *2016 ASEE Annual Conference & Exposition Proceedings*, New Orleans, Louisiana: ASEE Conferences, Jun. 2016, p. 26122. doi: 10.18260/p.26122.
[2] H. Perkins, A. Godwin, and E. Berger, "Potential of a Values Affirmation Intervention for Marginalized Gender Students' Belonging and Recognition".
[3] H. Budinoff and V. Subbian, "Integrating Asset-based Practices into Engineering Design Instruction".
[4] L. Chen, J. Zhu, and C. Zheng, "The Impact of STEM Extracurricular Learning Experiences on Freshman Engineering Students' Engineering Identity".
[5] S. Damas, "BSTiE: A Proposed Conceptual Framework for Black Student Thriving in Engineering".
[6] J. R. Morelock, "A systematic literature review of engineering identity: definitions, factors, and interventions affecting development, and means of measurement," *Eur. J. Eng. Educ.*, vol. 42, no. 6, pp. 1240–1262, Nov. 2017, doi: 10.1080/03043797.2017.1287664.
[7] S. L. Rodriguez, C. Lu, and M. Bartlett, "Engineering Identity Development: A Review of the Higher Education Literature," *Int. J. Educ. Math. Sci. Technol.*, pp. 254–265, Jul. 2018,

doi: 10.18404/ijemst.428182.
[8] D. M. Hatmaker, “Engineering Identity: Gender and Professional Identity Negotiation among Women Engineers: IDENTITY NEGOTIATION AMONG WOMEN ENGINEERS,” *Gend. Work Organ.*, vol. 20, no. 4, pp. 382–396, Jul. 2013, doi: 10.1111/j.1468-0432.2012.00589.x.
[9] K. L. Tonso, “Teams that Work: Campus Culture, Engineer Identity, and Social Interactions,” *J. Eng. Educ.*, vol. 95, no. 1, pp. 25–37, Jan. 2006, doi: 10.1002/j.2168-9830.2006.tb00875.x.
[10] K. L. Tonso, “Engineering Identity,” in *Cambridge Handbook of Engineering Education Research*, A. Johri and B. M. Olds, Eds., New York: Cambridge University Press, 2013, pp. 267–282. doi: 10.1017/CBO9781139013451.019.
[11] J. Swenson, E. Treadway, K. Beranger, and A. Johnson, “‘Let Me See What I Could Do’: Students’ Epistemic Affect When Solving Open-ended, Real-world Problems,” in *Frontiers in Education Conference (FIE)*, Lincoln: IEEE, 2021, pp. 1–8.
[12] J. P. Gee, “Chapter 3 : Identity as an Analytic Lens for Research in Education,” *Rev. Res. Educ.*, vol. 25, no. 1, pp. 99–125, Jan. 2000, doi: 10.3102/0091732X025001099.
[13] H. B. Carlone and A. Johnson, “Understanding the science experiences of successful women of color: Science identity as an analytic lens,” *J. Res. Sci. Teach.*, vol. 44, no. 8, pp. 1187–1218, Oct. 2007, doi: 10.1002/tea.20237.
[14] Z. Hazari, G. Sonnert, P. M. Sadler, and M.-C. Shanahan, “Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: A gender study,” *J. Res. Sci. Teach.*, p. n/a-n/a, 2010, doi: 10.1002/tea.20363.
[15] E. Treadway, J. E. S. Swenson, and A. W. Johnson, “Open-Ended Modeling Group Projects in Introductory Statics and Dynamics Courses,” in *American Society for Engineering Education*, ASEE, 2021, pp. 1–11.
[16] J. Swenson *et al.*, “Consideration for Scaffolding Open-ended Engineering Problems: Instructor Reflections after Three Years,” in *2021 IEEE Frontiers in Education Conference (FIE)*, Lincoln, NE, USA: IEEE, Oct. 2021, pp. 1–8. doi: 10.1109/FIE49875.2021.9637392.
[17] Yin, Robert K., *Case study research: design and methods*, 4th ed. SAGE, 2009.
[18] M. F. Belenky, B. McVicker Clinchy, N. Rule Goldberger, and J. Mattuck Tarule, *Women’s Ways of Knowing*. New York: Basic Books, 1986.
[19] R. A. Engle and F. R. Conant, “Guiding Principles for Fostering Productive Disciplinary Engagement: Explaining an Emergent Argument in a Community of Learners Classroom,” *Cogn. Instr.*, vol. 20, no. 4, pp. 399–483, Dec. 2002, doi: 10.1207/S1532690XCI2004_1.
[20] K. R. Muis, M. Chevrier, and C. A. Singh, “The Role of Epistemic Emotions in Personal Epistemology and Self-Regulated Learning,” *Educ. Psychol.*, vol. 53, no. 3, pp. 165–184, Jul. 2018, doi: 10.1080/00461520.2017.1421465.
[21] ABET, “Criteria for Accrediting Engineering Programs, 2022 – 2023,” Baltimore, E001 12-28-2020, 2022. Accessed: Nov. 10, 2022. [Online]. Available: https://www.abet.org/wp-content/uploads/2021/02/E001-21-22-EAC-Criteria.pdf