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‘Let Me See What I Could Do’: Students’ Epistemic Affect When Solving Open-ended, Real-world Problems

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Abstract— *This full research paper examines students’ epistemic affect, or their feelings about and within the doing of engineering, when encountering ill-defined problems in two of their first engineering science courses. Ill-defined problems are what students will encounter as professional engineers, but engineering students typically get little practice in their coursework at solving these types of problems. As students explained how they worked their way through the ill-defined and open-ended problems, we found evidence of both positive and negative feelings that arose, as well as descriptions of affective transitions, or shifts from one affect to another. Some of these transitions show evidence that students begin to regulate or anticipate these feelings as a result of repeated exposure to ill-defined problems. This work has implications for including the development of epistemic regulation as part of engineering students’ preparation for professional practice.*

Keywords—*epistemic affect, professional practice, ill-defined problems, homework, qualitative research*

I. INTRODUCTION

As engineering educators, one of our main goals is to prepare students for their careers as professional engineer. Much of the focus of this preparation has traditionally revolved around learning conceptual knowledge, solving canonical mathematical models, analyzing and interpreting data, and designing systems, physical objects, or solutions [1]. In the past two decades, this focus has expanded to include teamwork, ethics, and communication skills [2,3]. Recently, others in engineering education research have added metacognition [4], social responsibility [5], and empathy [6]. We argue that learning how to regulate epistemic affect is an essential component of learning how to effectively execute the above skills in a professional context.

Our research team, like our peers in science education [7,8], are dedicated to engaging students in authentic disciplinary activities of engineering, especially around mathematical modeling [9]. Specifically, we look to give students opportunities to solve “workplace” problems [10,11] that ask them to grapple with complexity and further develop professional engineering practices, like engineering judgement [12]. In this study, we argue that the feelings that students have while doing engineering, or their *epistemic affect* [13], are important to take into account and understand, and that part of

our students’ learning process is understanding how to regulate their feelings while solving complex engineering problems [14,15].

Our inquiry into affect began as members of the research team were examining retrospective student interviews for utterances in which the students described employing engineering judgement practices when solving an open-ended modeling problem (OEMP). For an example of such utterances, see Swenson et al. [16]. We noticed dynamic shifts in the feelings students expressed, typically recalling the anxiety they felt when starting the problem and the satisfaction and increased confidence upon completing it. One of the thoughts that stood out most to us was by a student, Cristina, in a December 2020 interview about solving three OEMPs during the Spring and Fall semesters of 2020:

I know this semester [Fall 2020], I wasn’t thrown in for a loop as much as the first time last semester [Spring 2020]. This time, it kind of felt like, okay bring it on, I guess. I did it once, I could try it again. It made me feel like, I don’t know. I did get a lot of confidence just from doing it one time last semester. So this time felt not like a challenge, but like, okay, let me see what I could do. [Cristina, Fall 2020]

Cristina starts by talking about how in her second semester solving OEMPs she “wasn’t thrown in for a loop as much,” and contrasts that to how she felt her first semester solving OEMPs. She indicates how her attitude towards approaching the problems shifted (“okay bring it on”) because of the confidence she gained from completing the OEMP the previous semester. This semester, she approached the problem seeing it less like a challenge but as an opportunity to “see what I could do.”

Cristina’s recollection, as well as similar thoughts by other students, piqued our interest in looking further into students’ epistemic affect [13,17], or their feelings about doing engineering, as well how students anticipated and therefore regulated their feelings as they solved similar problems. Our analysis addresses two research questions: 1) What is students’ epistemic affect when doing open-ended modeling problems (OEMPs) intended to scaffold the productive beginnings of engineering judgement? and 2) How does students’ epistemic

affect change from the first to the third time they complete an OEMP?

II. BACKGROUND

Our work builds off of the work that science and math researchers have done on epistemic affect [13-15,17]. In their work Jaber and Hammer, these authors argue “how affect and motivation are inherent in scientific inquiry” [17, p. 158] by examining biographies and ethnographies of famous and Nobel Prize-winning scientists. DeBellis & Goldin, after fifteen years of research, discuss how the “changing state of emotional feeling during mathematical problem solving” [15, p.133] has implications for students’ learning, development of mathematical knowledge, and attitudes towards math. They also suggest that the goal should not be to eliminate the frustration or anxiety associated with doing mathematics, but instead aid students in associating those feelings with accomplishment [15]. As our field of engineering utilizes a considerable amount of scientific reasoning and mathematical problem solving, we expected to see similar affective feelings from our students.

In this paper, we define epistemic affect as feelings about and within the doing of engineering, in parallel with the definitions for science found in Jaber, Hammer, and Radoff’s work [13,14]. Specifically, we examined the data for *epistemic affective expressions* [14], or words and expressions describing the experience of epistemic affect, such as frustration at an answer not feeling quite right or excitement in having an idea about how to better approach a problem. To be clear, epistemic affect is not just a feeling one has but is a feeling that comes from doing engineering thinking. For example, in Larry’s interview he states, “I think [the OEMP] was really cool because it had us use some of what we learned in Mechanics on a problem.” Here, Larry has a feeling about the OEMP but his feeling is not associated with the solving of an equation, assumption making, or assessing calculated results, and is therefore not epistemic affect.

We also use Radoff’s [14] *affective transition*, or a shift from one affect to another. Transitions, in the case of this paper, are usually from negative to positive feelings, such as frustrated to proud. In a few cases, we saw a transition to a more neutral feeling such as the transition from frustrated to “less frustrated” (Lane) or from positive to negative when students would run into frustration or confusion again. Of particular interest, some of the transitions include descriptions of *affective regulation* [13], the regulation of the feelings that occur in the doing of engineering. Examining the causes of transitions allows us to gain insight into what aspects of the problem design or solution process encourage students to practice management of their negative emotions.

III. METHODOLOGY

The data analyzed in this study are from a larger project investigating the productive beginnings of engineering judgment [16]. Engineering judgement is a professional engineering practice, synonymous with expertise, that is the “judgment to make a final call on the reasonableness of the analysis or design” [12, p.287]. In order to give students the opportunity to engage in engineering judgement, our instructors write problems that do not have a correct answer, in which

students create a mathematical model using knowledge they just learned in class to analyze a real-world object or system. We call these problems Open-ended Modeling Problems (OEMPs). Details of how students engage in engineering judgement and how our team of practitioners scaffolds OEMPs for their students can be found in our previous work and in other papers at this conference [16, 18-21]. What is most relevant to this study is that OEMPs are usually the first open-ended (meaning there is no one correct answer) problems the freshman and sophomore students enrolled in this study have encountered in their engineering science courses (meaning outside of design classes).

The eleven interviews analyzed in this study are from a larger data set of 35 retrospective interviews about how students went about solving their assigned OEMPs and their thoughts about the problem compared to other experiences they have had during their undergraduate engineering education to date. The main purpose of these interviews was to understand how students engaged in engineering judgement and their thoughts about the OEMPs. The eleven interviews selected for this study are all the interviews with students from Maroon University. These were specifically chosen as this is the only group of students who have been assigned OEMPs over the course of two semesters, first in their Mechanics I (statics) course (Spring 2020) and then their Mechanics II (dynamics) course (Fall 2020). In this paper, students are referred to by self-chosen pseudonyms.

The problem students were asked to solve in their statics course was centered around the iWalk 2.0 Hands-Free Crutch (more details about this problem can be found in previous articles [18, 19, 20]). In their dynamics course students solved two different OEMPs: a problem about a two-car collision assigned as homework mid-semester and then a group or individual final project examining a system of their own choosing. Students began all OEMPs by making assumptions to create a free body or impulse-momentum diagram. They then used the canonical mathematical models they had been learning in class to calculate quantities like internal forces in the crutch or initial speeds of the cars pre-crash that allowed them to draw conclusions about aspects such as material and diameter of a member or fault in the accident. Students were then asked to assess the reasonableness of their answer. Both the iWalk 2.0 problem and the final project began with individual portions before the group project. The car crash problem was assigned only individually.

A. Data Analysis

Our analysis was an iterative, multi-part process grounded in our data. Our process of identifying affective expressions began with the third author searching in the eleven transcripts for feelings such as anxiety, frustration, confidence, accomplishment, fun, or anything with a similar sentiment. The first and second authors reviewed the utterances she identified and made notations where they found affective expressions, affective regulation, or affective transitions. Utterances that were not epistemic were discarded. Reviewing these notes together, we identified two lists of terms – one of positive valence and one of negative valence. Negative emotions included anxious/anxiety, frustrated, confused, stressed,

dissatisfied, scared/scary, stuck, and overwhelmed/overwhelming. Positive emotions included excited, fun, proud, accomplished, happy, and relieved.

During the review of notes we also identified student shifts in affect or affective transitions. Using the techniques from discourse analysis and the method described by Radoff and Jaber [14], we identified words or phrases that signaled transitions from one emotion to another. In the quote by Cristina above, she transitions by using phrases such as “first time last semester” and “one time last semester.” Our list of transition words included first, initially, started out...and/but, but then, and then, more/less (as a modifier to the affective signal), this/last semester, after, and once. Naturally, not every instance of a transition word necessarily signified an affective transition.

Taking these three lists of words, the first author made a second pass through the data, identifying any utterances that may be affective expressions or affective transitions. These utterances were reviewed by the first and second authors to ensure that only instances of the words in the transcripts corresponding to epistemic affect were included for analysis. During this review, we began analyzing the affective transitions in segments, identifying each affective expression and transition phrase, and thus identifying what caused the transitions. We also uncovered additional affective expressions including enjoyed, confident, empowered, uncomfortable, flustered, impossible, and challenging. Lastly, we noted that some modifiers such as “not” changed the valence of the affective expression to the opposite of the word. We used the list of new words to make a third pass through the data. These multiple searches, reviews, discussions, and segmenting of the data allowed us to identify

and represent the sentiments of our participants to the best of our ability. The results of these iterative processes can be seen in Tables 1 and 2.

IV. DATA

A. Students’ Epistemic Affect

As students approached OEMPs, we saw evidence that their epistemic affect ranged from extremely negative to extremely positive, depending on the student and the stage of each problem. Across our eleven retrospective interviews, we identified 151 instances of expressions of epistemic affect in the transcripts, using the list of keywords described above. A summary of these is given in Table I below. As can be seen from the table, not all students’ descriptions of working through the OEMPs reflect the same amount of affect; certain students, even when prompted explicitly to explain how something that they described made them feel, did not describe affect. Other students spoke freely about the feelings that they encountered while completing the OEMPs. We also saw students using negative words such as “not” in front of both positive and negative expressions, therefore inverting their affective sense. For example Lane “wasn’t very confident” and Geoffrey found the problem “not challenging.” Our counting of those expressions can be found in the last line of the two sections in Table I below.

Negative affective expressions that we identified included feelings of stress, anxiety, frustration, and uncertainty that arose while completing the OEMPs. The source of many of these feelings was nicely summarized by Adam as he reflected on his experience. During the interview following Spring 2020 when

TABLE I. EXPRESSIONS OF EPISTEMIC AFFECT IDENTIFIED IN THE TRANSCRIPTS

Expression	Spring							Fall			
	Dylan	Rich	Larry Nguyen	Lane Marigold	Cristina	Adam	Geoffrey	Joe Wong	007	Lane Marigold	Cristina
Negative Affect											
Frustrated			2	4		1				8	
Confused			2	1	3				1	3	10
Stressed/stressful	1	1	1				2				
Scared/Scary							3				2
Stuck					1			1		7	1
Overwhelming/Overwhelmed				2						1	
Uncomfortable					2	1					
Flustered										1	
Impossible					1						
Challenge/Challenging						2	1			5	
Inverted (positive affective expression)							1			3	
Total Negative Expressions				32						43	
Positive Affect											
Excited				1					3		1
Fun									11	5	2
Proud	3									4	
Accomplished				1							
Happy	4			2	1					4	
Relieved			2								
Enjoyed	2			1				1	1	4	
Confident					1				3	8	2
Empower/Empowered		1			1						
Calm										2	
Inverted (negative affective expression)			2				1			1	1
Total Positive Expressions				23						53	

he completed his first OEMP, he responded to the prompt “How did this problem make you feel?” as follows:

Frustrated. Challenged. Just because.. I've... as engineers, so I think a lot of us like to know certain given things and have a right and a wrong answer. And not having any of those and not finding words of affirmation from my professors or that I'm doing this right, that was hard. [Adam, Spring 2020]

The words describing the epistemic affect in Adam's example above, and in the following examples, are bold. A sense of frustration was identified in four of our interview transcripts from three different students across the two semesters, making it one of the most common types of epistemic affect we identified.

As Cristina explained, the pressure to develop a model from a physical system and take ownership of it generated discomfort:

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. [Cristina, Spring 2020]

In addition to employing the word “uncomfortable” to describe how she felt, Cristina may also be giving us hints about her discomfort through her repeated use of the word “like” in this sentence.

As students made those decisions, they simultaneously had to grapple with the course concepts of which they were still developing an understanding. While students generally feel relatively comfortable with forces after taking physics, the potential need to include moments or couples in the rigid-body models of the crutch and its joints cause negative feelings and even anxiety for some students, as described by Geoffrey:

Well, I think I was looking at the AB member [of the crutch]. If we had it another...like there was already a lot of forces on it and adding a moment seemed like a little bit **scary** to maybe over-constrain it because looking at it, there's like already six forces on it, so there's three like, yeah I mean it would've been possible, but it seemed like it was adding a lot. Moments are **scary** to me kind of... [Geoffrey, Spring 2020]

However, despite these negative feelings, nearly all students that were interviewed also described experiencing positive epistemic affect. Dylan explained in Spring 2020 after completing his first OEMP, “I was **happy** with my work on the assumptions. I was **proud** that I was able to come up with my own design limits.” Lane told us in Fall 2020 that “I **enjoy** defining the system and then breaking it down and discovering this doesn't work.” Overall, students experienced positive feelings ranging from enjoyment as they worked through the problems to accomplishment, relief, or excitement as they made progress or overcame obstacles, and even pride or confidence in their ability to handle such a large challenge.

At different stages of working on these problems, the same student could display drastically different affective signals.

Despite Cristina's initial discomfort about making her own modeling decisions, her affect was quite different when approaching the group project portion of the iWalk OEMP:

Everyone gets to see how everyone else thinks about it like you it kinda opens... you're **happy** about it. [...] And so that was pretty cool. You got to see like the different effects of the model... like the different, like, like for our stance you chose a different stance, we got to see like the different force in it. [Cristina, Spring 2020]

B. Students' Affective Transitions

Naturally, if a student experiences both negative and positive epistemic affect during the course of completing OEMPs, then affective transitions must be occurring. Across our eleven interviews, we found descriptions of such transitions in 7 transcripts. In the following examples, the words describing the epistemic affect are bold, while the transition words are bold and italicized.

Cristina describes the affective transition that occurs when she resolved a part of her model that she was initially uncomfortable with:

Also like with the friction there's like friction on the floor felt like that was kind of like real life or like accurate because like the floors usually have friction. And like I know for my [first attempt] I didn't have any friction force and **I kind of thought those like weird**. Like I know it's standing still but there's still some...something in there. So **I felt better once** I'd placed that into the second individual assignment because I was like okay that was more like real life. [Cristina, Spring 2020]

Cristina's initial epistemic affect corresponds to the “affective signals of questions” described in Jaber & Hammer's work [13]: she experiences a sense of restlessness due to something about her model not feeling quite right. The word “once” signifies the transition in her affect: she modified her model by adding a force. After she makes that change, her restless feeling is resolved.

During her interview in Spring 2020, Lane gave an overview of the process of completing the OEMP that describes a number of shifts that take place as she worked through the iWalk OEMP in the spring. She started out:

Ok, so, um, looking at the project, uh, the problem for the first time was **very, very overwhelming** because I, we, I'd never done an open-ended problem like this and so the idea that I could just make assumptions and then use those assumptions to create calculations was very new and **very overwhelming**. So, as I started to do the project to create the FBD [free-body diagram], I did go through **a lot of frustration** because the assumptions I made didn't make sense in the calculations and I was getting either weird numbers or I couldn't solve for something and so there were a couple hours there of just **extreme frustration** of how to model this to make it possible to solve for and then **once** I got through that and got the model it was really... I really **enjoyed**

TABLE II. NUMBER OF AFFECTIVE TRANSITIONS THAT STUDENTS ATTRIBUTED TO DIFFERENT CAUSES

Cause of Transition	Spring							Fall				Total
	Dylan	Rich	Larry Nguyen	Lane Marigold	Cristina	Adam	Geoffrey	Joe Wong	007	Lane Marigold	Cristina	
OEMP structure or scaffolding				1			4		1			6
Making progress in an OEMP				1	3					1		5
Getting stuck or confused				1								1
Instructor reassurance			1						1			2
Completing an OEMP			1	1	1					2	1	6
Prior Experience with OEMPs in the Spring	N/A	N/A	N/A	N/A	N/A	N/A	N/A		5	2	3	10

seeing how the different calculations came out and how everything was going to work together and then we moved on...

The initial affect that she describes is quite negative: she felt overwhelmed and frustrated being asked to do something unlike anything she had done before in her coursework. The first significant shift in her affect is highlighted by the use of the word “once” - Lane worked past her “extreme frustration” to get to an answer, and then “really enjoyed” seeing it come together, which is a very positive affect. Lane continued her description of the process:

... When we moved on to the group project, there was a little *less frustration* because we already had seen it for a while and kind of understood it more and so there was a lot more just kind of analysis being made and that was really interesting because we saw how the analysis changed *and then* there was again that **little bit of frustration and confusion** at the end with the axial force and kind of understanding why our calculations led up to this small number. Um, but as a whole, this problem made me feel **very accomplished** because I felt like I could model something very, in my mind that *started out* as very complicated and I had the skills to then model and analyze it. [Lane, Spring 2020]

The second shift in Lane’s epistemic affect comes after she moves from doing the individual parts of the OEMP to the group project portion. The modifier “less” on the affective signal “frustration” signifies a change: compared to the individual portion, there is a positive shift in her affect (though “less frustration” is not quite as positive as “really enjoyed” that was used between the two portions). The reduced frustration allows her to see the analysis as “really interesting” - up until the point that the group hit a road bump. She uses “and then” to highlight the next transition, this time from positive to negative affect, that occurred when the group got a value out of their calculations that did not make sense to them. In her final sentence, she indicates yet another affective transition, denoted by “but” and “started out.” This final transition is once again from negative to positive, wherein the completion of the OEMP makes her feel “very accomplished.” Clearly, she experienced shifts both from negative to positive and from positive to negative affect throughout the process of completing first the individual and then the group assignments.

These examples illustrate the affective transitions that occurred during just the first of the three OEMPs that these

students completed. In each of the utterances that we identified as describing an affective transition, it is clear that the student is attributing a shift in attitude to a certain cause. If we revisit Lane’s shifts in affect, she recounts that the first shift occurred as she made progress on the OEMP, completing the individual portion of the assignment. Next, she describes the affective shift resulting from the iterative nature of the OEMP. Working with her group to repeat the analysis on their combined model was less frustrating than the individual part had been because she “had already seen it.” The next shift occurs when her group is confused about their answer, which returned her to a level of “frustration and confusion.” Despite this, she attributes the final shift in her affect to completion of the project.

As illustrated by our motivating quote from Cristina described in the Introduction, students also experienced transitions across semesters and OEMPs. Cristina’s shift described in that quote was from feeling “thrown for a loop” to a level of confidence that made her address the challenge with a “bring it on” attitude. A summary of the causes students attributed their affective transitions to is shown in Table II: in 21 utterances, we identified 30 affective transitions that were described. As illustrated above with Lane’s account, a single utterance may represent multiple affective transitions: all four of the entries in her column from the Spring interview come from that one long quote.

The majority of affective transitions that we identified in the transcripts were experienced as positive shifts in epistemic affect. Table III summarizes the direction of the shifts for the transitions identified in Table II. The four negative shifts described were (1) Lane’s instance of getting stuck, (2) an instance of Geoffrey feeling that the final iteration of the OEMP in the Spring was one iteration too many, and (3-4) two quotes from 007 both describing an interesting shift between semesters: in each utterance, she nearly simultaneously describes within the same quote how seeing an OEMP in the Fall after doing her first one in the spring was “a little daunting from the last one” but also that “I knew that they, that they were coming and I was pretty excited because, yeah like I said they were more fun.” Her prior experience causes her to hold conflicting feelings, such that we have included this quote as two separate transitions, one with affect becoming more positive (she is now excited) and one with

TABLE III. DIRECTION OF AFFECTIVE TRANSITIONS.

Affect becomes more positive	Affect becomes more negative
26	4

it becoming more negative (she finds it daunting because of her prior experience). The second quote features the same contrast (daunting/fun) and was treated in the same manner.

While many of the transitions to more positive affect are relatively fleeting feelings associated with pleasure in seeing hard work pay off, reduced stress due to iterating on the problem in the Spring, or assurance from the instructor that there was not a single correct solution, other utterances describe more profound transitions. Take for instance Cristina's "let me see what I could do" from the Introduction or Lane's description below, both of which explain fundamental transitions in how they address challenges in a mechanics course between the Spring and Fall:

I was **very flustered** when I was handed the first open-ended problem. And it took me a long time to understand the assumption making and the reassessing. So going through that *last semester* really helped me, really prepared me for going through it this past semester, because I went into it understanding how to approach it. I didn't go into it getting **flustered**, I mean like, "I don't know what to do." I was a lot **calmer**. I could think through it a lot easier, even though you run into problems and you get **stuck** and everything, but I expected it this time. [Lane, Fall 2020]

Neither Cristina nor Lane seem to expect the technical challenge to be any smaller in Mechanics II, but they demonstrate evidence of developing awareness of and preparation for the feelings that accompany it: the challenge of open-ended modeling is expected, and they can practice affective regulation to mitigate the negative feelings that they anticipate may arise.

V. DISCUSSION

The very first student outcome identified by ABET is "an ability to identify, formulate, and solve complex engineering problems..." [1]. In interacting with students, most engineering educators are often privy to the feelings of frustration, stress, and eventually accomplishment that students experience when working through complex engineering problems. It is clear from our interviews that OEMPs are no exception: OEMPs provide students with ample opportunities to experience both positive and negative epistemic feelings while completing them. Some students' descriptions clearly illustrate that such feelings were more prevalent while doing these problems than they are while tackling typical textbook problems. The feelings of frustration, confusion, and excitement are similar to feelings found when examining students doing science [7,14,17]. The strongest parallel we see is between OEMPs and Engle & Conant's [7] work in productive disciplinary engagement because in both, students have agency to define the scope of their problem. In our data, students described the freedom they had to decide how to go about solving the problem [22], in some cases in very disciplinarily authentic ways. While we did not witness our students having passionate emotional displays like the students in Engle & Conant's [7] work, our students did recount being "very frustrated" and "very, very proud."

If the novelty and complexity of problems does in fact increase the likelihood that students must deal with feelings that arise while doing them, then giving students opportunities to

practice managing their feelings is essential to training them to succeed as engineers who can tackle complex real-world problems. We see ample evidence that completing the OEMPs provided practice at affective regulation. In her second interview, Lane conveyed this very explicitly:

But if I do this, if I walk away, if I come back, if I just start the problem completely over, which I did multiple times, and I just try a different attempt or a different method, even though it might not lead somewhere, putting all of those attempts together will get me to my final idea like, "Okay, now I understand how to do it." And so, I did that for every open-ended problem in both Mechanics 1 and Mechanics 2. And just helped me learn more about my process in addition to the concepts. [Lane, Fall 2020]

As Lane suggests here, providing exposure across semesters to very open-ended problems is one way we can help our students practice affective regulation. Cristina and 007 also expressed similar sentiments in their descriptions of affective transitions that they experienced across semesters.

In addition to providing opportunities for students to get frustrated and stuck, and to manage those feelings, we see evidence in students' accounts that assignment design and implementation practices can assist them with affective regulation. As is clear from both the interviews and from anecdotal statements in office hours, students appreciate explicit acknowledgement of the discomfort that this type of open-ended modeling can create and reassurance that there really is not a single correct answer that they should be striving to achieve. Our Spring interviews also suggest that the iterative and/or group nature of the OEMP that was assigned in Mechanics I may have helped students recognize that, while challenges will come up, they have the ability to manage the negative feelings and work through them to come to an answer. For certain students, we see that the ability to select a system of their own choosing for the final project in Mechanics II created initial feelings of excitement, which may help mitigate the negative feelings that arise when they get stuck.

Affective regulation is one aspect of *meta-affect* [15], or students' "awareness and management of the experience of feelings" [13, p. 194]. We hypothesize that through practice at affective regulation, OEMPs may provide a productive venue for students to experience meta-affective learning, or "how productive meta-affect stabilizes over time" [14]. It is notable that three of the four students interviewed in the Fall described transitions related to having done OEMPs in statics during the Spring semester, and that a total of ten such transitions were described (eight of them consisting of a net positive shift in epistemic affect). While we only have interviews across both semesters with two of our participants, both of those interviews support this hypothesis. As Cristina describes during her interview in the Fall, the confidence in tackling challenges that she built through the OEMPs extended beyond the limits of that problem type:

I know the first problem, I was really hesitant about things and now I felt better about it. And just better about everything in general. In Mechanics itself, as long as I was confident and followed what I knew was

the principles, and then just followed it, I would be okay. [Cristina, Fall 2020]

Our research team also sees ties between students' epistemic affect and the formation of their engineering identity. While we have not yet begun to explore these links, students were explicitly informing us they saw these connections while completing OEMPs, telling us these problems "[help] me develop as an engineer [Joe, Fall 2020]," they "kind of give me this internal understanding of what I want to be [Lane, Spring 2020]" and "the open-ended problems solidify whether or not you want to be an engineer [Lane, Fall 2020]" and were "the most engineering thing we've done so far [Cristina, Fall 2020]."

It is worth noting that our methods of exploring students' epistemic affect and their transitions between different affective states have certain limitations. For one, our dataset is limited to retrospective interviews, and students' recollections of their feelings is imperfect and limited to what they choose to recount, or become aware of during the interview reflection [23]. However, given the length of time spent by students performing these OEMPs, it would be impractical to capture the process in its entirety. Second, while our keyword search technique allowed us to analyze a large number of transcripts, it also has inherent disadvantages: despite our iterative and data-based approach to building our list of affective expressions and transition phrases, we acknowledge the inevitability that we did not capture every single instance of affect or affective transition present in the transcripts. Additionally, in some previous work on affect (e.g., [13]), analysis of not only the text of the transcript but also of facial expressions and gestures has yielded insight.

VI. CONCLUSIONS AND IMPLICATIONS

In this work, we examined the epistemic affect that students experienced while doing OEMPs, as conveyed in interviews spanning two consecutive semesters. As a single cohort of students completed OEMPs in first their statics course and then their dynamics course, we see that they experienced a variety of both positive and negative emotions that arose during the problems. These feelings shift throughout the process of completing the problems; in certain interviews, explicit descriptions of these affective transitions give us insight into the causes of such shifts. In some cases, the transitions described are fleeting; in others, they represent a developing ability to regulate the negative emotions that arise while completing an authentic disciplinary task like modeling.

From an instructional standpoint, we believe that the engineering curriculum (even outside of design classes) should have more assignments that challenge our students - not in terms of computational complexity or problems meant to trick them, but with challenges of the type that ask students to engage in an authentic disciplinary task that invokes realistic engineering thought processes. Not only do such assignments help students develop the technical skills associated with the task, they also provide practice at regulating the emotions that come with that task in its complexity, and often, its ill-defined nature. However, our assessment of students' accounts of their affective transitions while completing such assignments suggests that instructors must recognize students' affective states, support them through periods of negative affect, and help students to practice regulating those emotions. This attention and support

paired with providing challenges is consistent with helping students remain within the Zone of Proximal Development [24].

Some of this support can come in the form taken by the assignment itself. Early in our research team's analysis of interviews about OEMPs (pre-dating the interviews in this paper), we noticed strong feelings of anxiety associated with completing the problems. How to scaffold the OEMPs to make them less overwhelming has been an ongoing conversation that we and our collaborators have been having [21]. Aspects of scaffolding cited by students as instigators of positive affective shifts in the data we have presented in this paper include iteration on a problem alone and in groups, and the assignment of multiple open-ended problems across multiple related courses. Iteration on scaffolding for the problems described here is ongoing, for example with the addition of ungraded drafts for each of the individual parts of the OEMP assignment in Spring 2021 that we suspect will further reduce anxiety.

Other aspects of this support come in the way the assignments are introduced and framed within the context of the course, and the reassurance or support that is provided to students as they work through them. In these accounts, we have two separate students who tell us that simply being reminded that the problem does not have a correct answer at a key moment that they felt significant negative epistemic affect caused them to experience a shift towards the positive, reducing the anxiety that they felt being asked to develop their own model for the first time. These shifts align with "the power of caring support in instilling the confidence with which to meet difficult challenges" [25, p. 24] observed in other fields such as teaching English as a Second Language.

Our findings provide a starting point for examining the importance of studying affect in helping students prepare to tackle complex challenges as professionals. From our examination of Cristina's journey through two semesters of Mechanics, we begin to see evidence that she believes the OEMPs contributed to her confidence in approaching all types of mechanics problems, not just open-ended ones. As we continue this work, we hope to be able to identify other instances of meta-affective learning arising from the practice at affective regulation that this type of complex problem provides, and to better understand how to help students along the road from affective transitions to stable meta-affective learning. While we have examined a single type of complex problem that students might encounter, further research is also needed to study affective regulation in other types of problems, including in design projects which are so ingrained in the engineering curriculum.

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