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Development of a Survey Instrument for Measuring Affective Pathways

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Abstract

This research paper examines a pilot survey question to measure students' affective pathways when solving open-ended, ill-defined modeling problems. Research on affect in mathematics has discovered that students' emotions tend to fall into familiar patterns, or *affective pathways*, that students have developed over time. These pathways are in part influenced by their *global affect*, or student attitudes and values about a subject. It is inevitable that frustration will occur at some point when solving a challenging problem; however, from the point of frustration, some students experience *positive pathways* in which they move from those challenges into eventual satisfaction, while other students' affect falls into *negative pathways* that move from anxiety into fear or despair and rote procedures or avoidance of the problem. Just as students' global attitudes influences the emotions experienced throughout the problem, the traces of the affective pathways over time can in turn influence global affect - following a negative pathway repeatedly can, over time, build global hatred of themselves or the subject.

These affective pathways have typically been assessed primarily through qualitative methods. In this study, we sought to measure students' affective pathways while undertaking ill-defined problems in engineering science courses. We included a pilot question in a survey given to students at three universities in four different courses solving open-ended modeling problems in one semester, asking them to drag and drop positive and negative affective words derived from our prior work into the pathway they took when solving the problem. Our goal in piloting this survey question is to have an effective way to measure students' affective pathways at scale in situations across their engineering education, in order to understand the implications on their global affect about engineering. We believe that the development of an effective tool for measuring affective pathways will facilitate future studies on retention in engineering.

Keywords: affect, emotions, problem-solving, undergraduate engineering

Introduction

This research paper examines a pilot survey question developed to measure students' affective pathways when solving open-ended, ill-defined modeling problems [1], [2]. Our previous analysis of student affect while solving ill-defined problems meant to practice engineering judgment found that engaging with these problems causes students to experience both strong negative (frustration, stress) and positive (pride, happiness) feelings [3]. These feelings experienced in the course of problem solving are known as *local affect* [4], [5], and are similar to the feelings that have been observed elsewhere in mathematics, science, and engineering education [4], [6]–[9]. Having found these feelings in qualitative interview data, our research team now wants to find a manageable method to measure the local affect of entire classes of students.

Research on affect in mathematics has found that students' local emotions tend to fall into familiar patterns, or *affective pathways*, that students have developed over time [4], [5]. These pathways are in part influenced by their *global affect*, or student attitudes and values about a subject [5], [6], [10]. It is inevitable that frustration will occur at some point when solving a challenging problem, even for experts; however, from the point of frustration, some students

experience *positive pathways* in which they move from those challenges into eventual satisfaction, while other students' affect falls into *negative pathways* that move from anxiety into fear or despair and can cause them to resort to rote procedures or avoidance of the problem [5]. Just as students' global attitudes influence local affect, repeating local affective pathways over time can in turn influence global affect—following a negative pathway can over time build global hatred of themselves or the subject [5], [10].

Affective pathways have typically been assessed primarily through qualitative methods [10]–[12]. Our goal in piloting this survey question is to have an effective way to measure students' local affective pathways at scale in order to understand the implications on their global affect about engineering. Mathematics researchers have suggested that it is important to provide students practice at handling negative emotions, coming back from frustration to experience pleasure, and interrupting negative feelings [5]. Because complex engineering problems have the potential to bring up strong feelings (including negative feelings) [3], we believe that it is equally important to study the interruption of negative pathways in engineering students as in math students, particularly since eventual development of negative global affect about engineering may have implications for student retention. However, we can only explore how to interrupt negative pathways if we know how to measure them. In this study, we piloted a survey question designed to measure the affective pathways that students experienced. We included the question in a survey given to all students in four different courses at three universities about their experiences solving open-ended modeling problems in one semester. This work examines the responses from that pilot survey question in order to answer the following research questions:

(1) What common affective pathways do we see students describing?

(2) To what extent do our pilot survey questions reveal distinct positive and negative affective pathways that parallel the idealized pathways found in mathematics education literature?

Background

An affective pathway is a sequence of local affective states experienced as one solves a problem [4], [5]. Based on his experience and observations of students solving problems in mathematics, Goldin described two "well-traveled" affective pathways, one positive and one negative, which consist of sequences of local affect that problem-solvers may experience while performing a mathematical problem-solving activity [5]. In both pathways, problem-solvers start with feelings of curiosity, followed by puzzlement and then bewilderment. In a negative pathway, this can yield to frustration at a lack of progress, anxiety, and eventually to fear and despair. In a positive pathway, however, the problem-solver finds an approach which moves them from bewilderment into encouragement, pleasure, elation, and finally satisfaction at the completion. While these two pathways are idealized models, Goldin's collaborator DeBellis noted that an affective pathway "may include [...] repeated emotions, loops of emotions which form a sub-sequenced pathway, as well as interactions between positive emotions and negative emotions…" [4] (p. 32).

The affective states making up such a pathway can have varying magnitude and direction (also called activation and valence [7]) as well as duration, and students may be more or less aware of or in control of the emotional states [6]. In this work, we will utilize the term "valence" instead of direction to describe whether a single emotion is positive or negative, and the term "direction" will be reserved for describing entire pathways. Local affective states are important for several

reasons: first, they are known to interact with cognition/understanding and the problem-solving process [5], [6]. Second, they are believed over time to contribute to the alteration of a student's global affect about the subject—students who begin to trace and retrace negative pathways may over time find their feelings and attitudes about mathematics becoming more negative, or vice-versa becoming more positive if they trace positive pathways [5], [10]. For this reason, Goldin highlights the importance of interrupting the negative feelings, providing students ways to overcome negative emotions and get practice coming back from frustration to pleasure [5]. We believe that these same interactions between local and global affect are likely at play in engineering problem-solving, as well.

Our motivation for undertaking this work stems from our involvement in a larger project studying the implementation of Open-Ended Modeling Problems (OEMPs). OEMPs are a type of assignment designed to encourage students to develop engineering judgment [1]. Real-world engineering problems as solved by engineers are ill-defined, with solutions that are assessed by socio technical metrics and often involve complex mathematical models [13], [14]. In contrast, the problems students typically solve in engineering science courses (core technical courses such as fluid mechanics, statics, and controls) are well-defined, asking students to find a single correct answer. While well-defined problems are important to build fluency with equations and mathematical competency, they do not prepare students for the kind of problem solving they will be asked to do as professional engineers. Our previous qualitative analysis of interviews with students about solving OEMPs revealed that some students experience extremely strong emotions while undertaking them [3]. Based on parallels between affect in the engineering and mathematics education literature ([3], [7], [15]) we believe that aiding students in moving towards positive pathways is also essential in engineering, particularly in the context of problems like OEMPs that may heighten those emotions.

Methods

Survey Question

Our survey question is adapted from previous research in mathematics education. Gómez-Chacón developed a question adapted from Goldin's original pathways [5] in which she asked students to choose which emotional pathway best fit their experience while solving a problem: they could choose between "Affective pathway 1 (enabling problem solving): curiosity → puzzlement → bewilderment → encouragement → pleasure → elation → satisfaction → global structures of affect" and "Affective pathway 2 (constraining or hindering problem solving): curiosity → puzzlement → bewilderment → frustration → anxiety → fear/distress → global structures of affect," or could describe their own pathway if they did not feel that either option fit their affective experience [16] (p. 210).

We found these two choices a bit extreme, and hypothesized giving students only these two choices may not feel representative of their pathways, but that completely student-described pathways would be difficult to analyze efficiently. Instead, we chose to provide students with a list of words and asked them to put them in the order that best represented their emotional pathway through the problem. To determine what emotions to include, we compared the list above (the idealized pathways used by Goldin and Gómez-Chacón) to the affective expressions we previously found from examining retrospective interviews about ill-defined statics and dynamics modeling problems [3]. We added the words *confusion*, *accomplishment*, and *pride*, as

we saw a gap in the existing list of words to express those feelings. We removed *elation* and *fear/distress*, as those were more extreme words that didn't fit with the affective expressions observed in our previous work with engineering students. As this was a pilot question, we also gave the students an option to add a word of their choosing by listing *[emotion not listed here]*, and we gave the opportunity for students to provide us with the word in the next question in order to collect common words that students might want as part of the list in the future ("If you used [emotion not listed here] above, what word or phrase did you need?"). The final question presented to students is shown in Figure 1, with the emotions listed in the order shown.

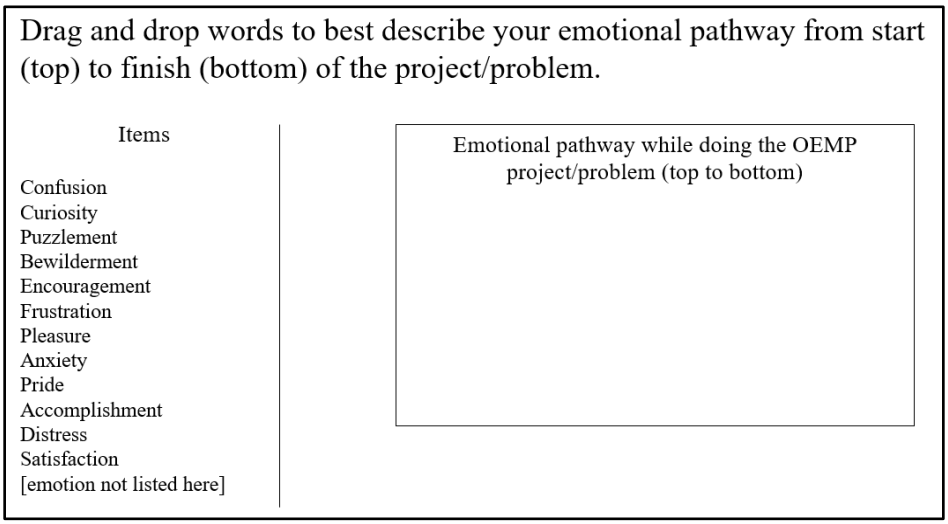

Figure 1: The pilot question as presented to students in the Qualtrics software

Data Collection

Students from four classes at three universities were assigned OEMPs in their classes as part of a larger research project [1], [2], [17]. The scope and format of the OEMP(s) assigned in each class varied, as shown in Table 1 below.

Table 1: Pilot survey question participation. Of 188 students who consented to the survey across the four classes, 161 completed the drag-and-drop question.

University	# Completed Question/# in Class	Course	Type of Open-ended Problem(s) or Project Assigned
Maroon University	22/36	Mechanics II (Dynamics)	1 End-of-Semester Project
Gold University	18/~300	Statics/Mechanics of Materials	3 Problems throughout Semester
Purple University	116/234	Statics	1 Semester-long Problem
Purple University	5/81	Road Vehicle Dynamics (RVD)	3 Problems throughout Semester

The students were invited to complete an anonymous survey including our pilot question and twelve other questions about the OEMPs on the online Qualtrics platform. Students at Maroon University and in the Statics course at Purple University took the survey during class time (on the day of the project presentations for Maroon University and the second-to-last day of class at

Purple University), while students at Gold University and the Road Vehicle Dynamics (RVD) class at Purple University took the survey from a link posted on their course management site at the end of the semester. Due to the anonymous nature of the survey, we cannot draw any connections between survey responses and course performance.

Analysis methods

Wherever possible, our research team assigned valence to the emotions in a manner consistent with Goldin's descriptions [5]. Therefore, encouragement, pleasure, and satisfaction, as well as our additions of accomplishment and pride, were taken to have a positive valence. Similarly, frustration, anxiety, and distress, and our addition of confusion, have a negative valence. Puzzlement, though, is described as a neutral emotion, without "unpleasant overtones" [5]; bewilderment has the potential to be neutral or to take on negative valence, depending on interpretation, but was taken to be neutral for the purposes of our analysis. Curiosity, which was not included in Goldin's work, is also taken to be neutral, though arguably some might interpret it to have a positive connotation. The valence of the *[emotion not listed here]* responses was determined on a case by case basis, as agreed upon by all three authors.

As a preliminary analysis of the direction of the pathways, we analyzed patterns in the last two words that students selected for their pathways. Using Goldin's work as a guide [5], we determined to count a pathway as overall positive or negative in direction when it ended in two positive or two negative words, respectively. Cases that end with only one positive or negative word were labeled "slightly positive" or "slightly negative," as they do not have a strong positive or negative direction. If the string of words ended in a neutral word, the overall pathway was labeled as neutral. Pathways of length 1 could naturally only be slightly positive, slightly negative, or neutral, since they cannot end in two positive or negative words.

Results

Of the 161 responses to the drag-and-drop pilot question, 66.5% (107 respondents) used between 3 and 5 words to describe their emotional pathways, as shown in Figure 2. A very small number of students (4) selected only a single emotion; while these are arguably not "pathways," we elected not to exclude them from our analysis because they represent such a small fraction of the responses that they would not significantly change any results. Note that the option *[emotion not listed here]* is counted as a single word for this tally, regardless of what the student wrote in the following open-ended response about what emotion was needed.

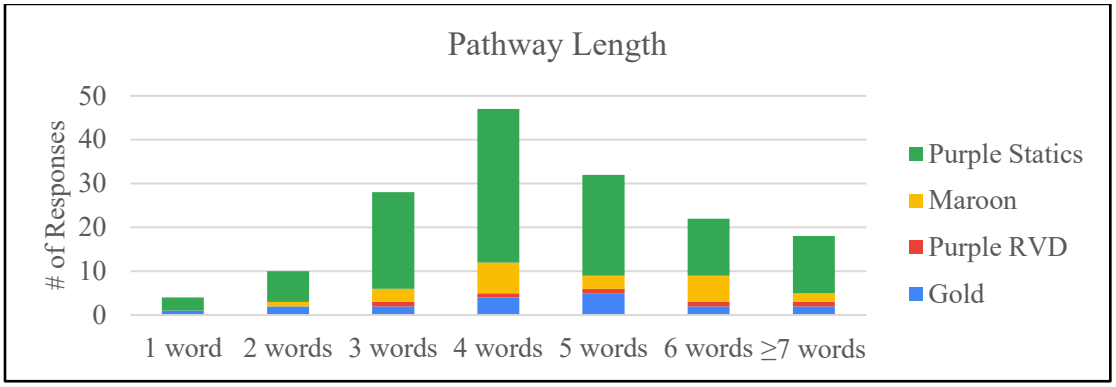

Figure 2: Number of words used by respondents to describe their emotional pathways.

The majority of students chose to construct pathways using the provided words; only 14 responses employed the *[emotion not listed here]* option, which is less than any emotion we provided, as can be seen below in Figure 3. The most-employed word was *confusion*, which 116 students included in their emotional pathways, followed by *accomplishment* (98 uses) and *curiosity* (90 uses).

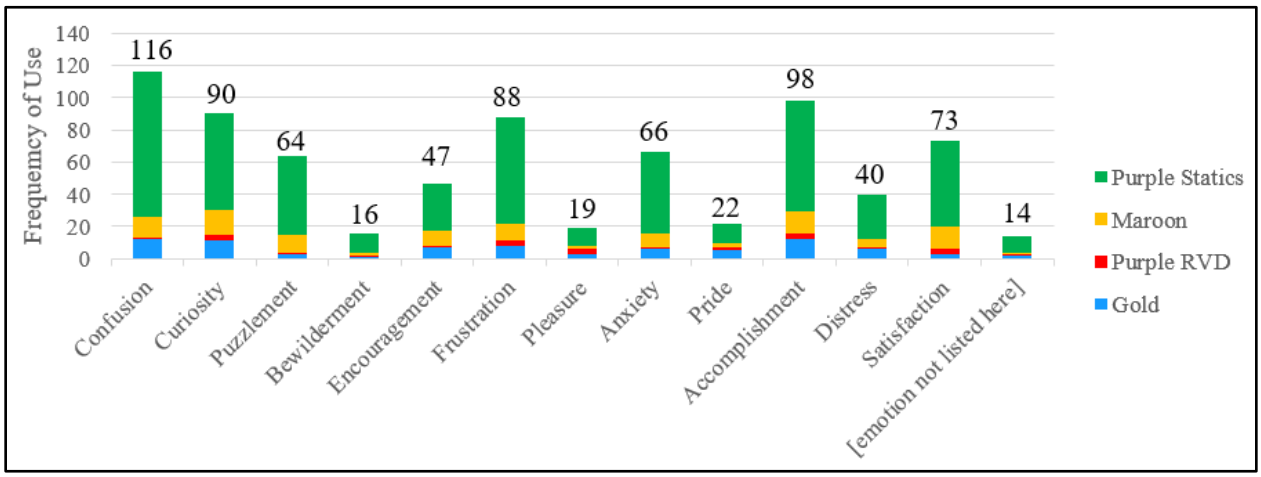

Figure 3: Number of responses employing each available emotion.

Results from the *[emotion not listed here]* follow-up question "If you used [emotion not listed here] above, what word or phrase did you need?" did not reveal any obvious emotions that should be added to the question. Of the 14 students who placed it in their pathways, 8 wrote phrases or sentences instead of single emotions. By consensus of the authors, 4 of the responses were deemed to be neutral, 3 were positive, and 7 were negative. In addition to these 14 responses, a few additional students wrote words or phrases in the follow-up question despite not having dropped *[emotion not listed here]* into their pathways; those student-provided words were excluded from our analysis and only the ordered pathways were analyzed, since we had no context for where in the pathway they may have occurred.

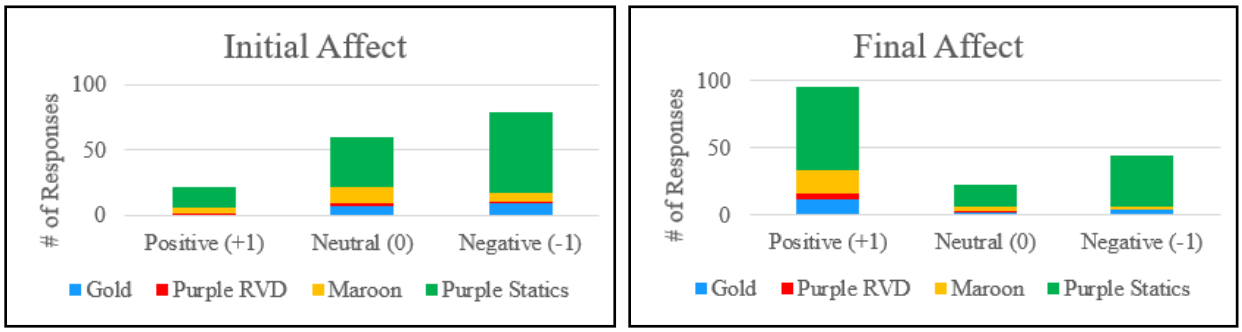

Figure 4: Valence of initial (left) and final (right) affective states for each affective pathway described.

The starting and ending affective states described in our results are summarized in Figure 4, with each word reduced to its valence. Of the 161 responses, 13.7% started with a positively-valanced

emotion, 37.3% began with a neutral emotion, and 49.1% began with a negative emotion; final affect was higher on average: 59% positive, 13.7% neutral, and 27.3% negative. Comparing across courses in which the survey was administered, the trend towards higher final affect than initial affect appears fairly consistent, though the precise breakdown of students starting and ending with each valence varies. Comparing the initial and final affective states for each individual respondent, 63.4% reported higher affective valence at the end of their pathway than at the beginning, while 13.0% had a lower valence and the remaining 23.6% started and ended with the same valence (note that the 4 pathways of length 1 are necessarily included in this last group).

Our analysis of the overall pathway direction examined the last two emotions as described in the Methods, not just the final affect. Out of the 161 responses, 39 of the pathways were determined to be ambiguous or neutral, 34 slightly positive, and 14 slightly negative as shown in Table 2. 58 pathways were clearly positive and 16 negative; out of these 74 clearly polarized pathways (ending in 2 words of the same valence), 78% were therefore positive.

Table 2: Pathway directions, based on analysis of the valence of the last two emotions listed.

Positive (2+)	Slightly Positive (1+)	Neutral	Slightly Negative (1-)	Negative (2-)
58	34	39	14	16

As can be seen in Table 3 below on the row labeled "Uses as Initial," most students described pathways starting in one of two emotions: *curiosity* (49 responses) or *confusion* (44). For the 49 students who described *curiosity* being their initial emotion, 65% subsequently experienced a pathway that we coded as having a positive direction (2+) and only 4% experienced a negative pathway (2-); the remaining pathways were slightly positive, slightly negative, or neutral. This contrasts with starting with *confusion* (44 instances), after which only 39% experienced a positive pathway and 16% experienced a negative pathway. While we cannot assess causation based on the survey question given, these results suggest that students who started with *curiosity* were more likely to experience positive affective pathways, while students who started with *confusion* were more likely to experience negative affective pathways.

Table 3: Words employed in drag-and-drop affective pathways, along with their valence (+1 for positive, -1 for negative, and 0 for neutral) and their frequency of use as the initial or final emotional state.

Emotion	Confusion	Curiosity	Puzzlement	Bewilderment	Encouragement	Frustration	Pleasure	Anxiety	Pride	Accomplishment	Distress	Satisfaction	[emotion not listed here]
Valence	-1	0	0	0	+1	-1	+1	-1	+1	+1	-1	+1	?
Uses as Initial	44	49	8	1	1	11	1	18	0	11	3	8	6
Uses as Final	15	4	12	2	2	9	2	11	14	41	7	35	7

The final emotions listed in the emotional pathways also had two responses much more popular than the others (see Table 3, "Final"): *accomplishment* (41 responses) and *satisfaction* (35). When the pathway ended in *satisfaction*, the emotion immediately preceding it was listed as *accomplishment* 60% of the time; this trend is similar to the end of Goldin's positive pathway [5], where *elation* leads to *satisfaction*, although accomplishment is perhaps not as strong as elation. For the pathways ending in *accomplishment*, the preceding word was more varied: most common were *satisfaction* (27% of the time) and *confusion* (15%).

Discussion

A majority (58%) of students began the pathways that they described in our drag-and-drop survey question with either *confusion* or *curiosity*. An open question for future investigation is whether they were so popular as initial words because they truly represented the starting emotions that students experienced when tackling the OEMP(s) in their courses, or whether it was simply because they were listed first in the presented question (Figure 1). To address this in future work, we plan to either present the words alphabetically or randomize the order in which they appear.

Our survey added the words *confusion*, *accomplishment*, and *pride* to the words we took from the idealized pathways [5] based on their frequency of use in our previous work [3]. In our results, two of these (confusion and accomplishment) were the most commonly used words in the pathways that students constructed; this shows agreement between these survey results and our previous qualitative findings. The fact that Goldin did not include these words in his pathways and we saw them so commonly used by our students may be attributable to the twenty-year difference between the two studies, and possible changes in common vernacular. Another possible reason could be the differences in the kinds of problems the students were solving, as Goldin's participants were solving mathematics problems and our participants were solving engineering problems.

One of the most striking findings in our results that warrants further study is the potential for the initial emotion to influence the overall pathway direction, as evidenced by the differences in pathway direction for the common initial emotions *confusion* and *curiosity*. We hypothesize that one of two things likely occurred: (1) that students' positive pathways influenced the way they retrospectively reported their experiences, resulting in pathways that started with curiosity instead of confusion, or (2) that the students who began the problem with curiosity already had more positive global affect about engineering, and were therefore more likely to trace positive pathways. In support of the second possibility, Jaber and Hammer [18] have previously emphasized the importance of curiosity in science and engineering education: "Taking up the pursuit means, in part, becoming driven by feelings of puzzlement and curiosity…" (p. 195). If the way that students approach the problem is a cause rather than simply a correlation, this is a potential area where the scaffolding and presentation by the instructor may be able to influence students' affective experiences. Additionally, since we added *curiosity* to the list of emotions that originally made up the idealized pathways on which our question is based, we attributed a neutral valence to it (in the absence of literature on whether it has positive or negative valence); it is possible that a positive valence would have been more appropriate.

One of our goals in this work was to compare the pathways that students dragged and dropped via this survey question to the idealized pathways described in the mathematics education literature. We saw commonalities in the starting emotions that students chose with the ideal pathways—Goldin's typically start with *curiosity*, which was also the most common starting word chosen by students. However, we also found that a lot of students started in *confusion*, which is not an affective state included in Goldin's pathways; confusion is not far from puzzlement and bewilderment, which come 2nd and 3rd in the idealized pathways.

There were also notable similarities in ending emotions between our data and the ideal pathways: Goldin's positive pathway ends in *satisfaction*, and we found that *satisfaction* and *accomplishment* (our addition to the list of affective states, but with a similar meaning) most frequently ended students' self-described pathways. Our negative pathways were somewhat less similar to the ideal pathways, however, with confusion being the most common negatively-valenced final emotion selected (as previously discussed, confusion was not employed in Goldin's work, but is similar to the puzzlement or bewilderment he describes towards the beginning of the pathways). We can hypothesize a number of factors that may contribute to this. First, the dataset of positive pathways is simply larger than the dataset of negative pathways: we had 92 positive or slightly positive pathways and only 30 negative or slightly negative pathways in our dataset; this is unsurprising, as the instructors specifically attempted to scaffold the OEMPs to avoid negative student experiences. Second, we did not include the option *fear/despair* in our survey question, which is how the idealized negative pathway ends. Another possible contributing factor to differences from the idealized negative pathway could be that some of these negative emotions in our results are derived from group work struggles (something we see students write about in the other questions from the same survey) but which was not an element in Goldin's studies of affect and problem-solving.

Conclusions

What common affective pathways do we see students describing?

The majority of the pathways that students described had a positive direction, ending in one or more positively-valenced emotions (typically *satisfaction* or *accomplishment*); this is encouraging as it suggests that the OEMPs for which students were describing pathways may encourage progress towards or reinforcement of positive global affect about engineering. Many pathways began with either *confusion* or *curiosity*; those that started in curiosity tended to be more likely to end positively than those that began with confusion.

To what extent do our pilot survey questions reveal distinct positive and negative affective pathways that parallel the idealized pathways found in mathematics education literature?

Comparing the pathways that our participants described to Goldin's idealized pathways [5], the pathways described by students tended to be shorter on average: most commonly, students used 4 words, whereas Goldin's ideal pathways include 6-7 emotions. The agency we provided in letting students create their own pathways means many times students described very short pathways (1-3 emotions) which are necessarily difficult to classify as positive or negative. And while some longer pathways were clearly positive or negative, many were not distinct (coded as slightly positive, slightly negative, or neutral); as complex as these problems are, it is unsurprising that we see loops or sub-sequences [4] that do not resolve nicely into positive or negative pathways. However, despite this complexity, we did see significant overlap between the

words that students used to start and end their pathways and the ones at the start and end of the idealized pathways, providing some support for Goldin's idealized pathways that were "not directly derived from clinical research" [5] (p. 212).

Implications and Future Work

Our goal in undertaking this research was to improve our ability to understand how to move students towards positive pathways that will encourage the development of more positive global affect about engineering. We believe that this has potential for positively influencing retention in engineering. The results from our initial implementation of a survey question to measure affective pathways are promising: rather than limiting students to the choice of two idealized options [16], a drag-and-drop format allows students to describe more realistic pathways that do not follow a linear progression of affect. We believe that this agency will enable us to more accurately capture student experiences that we can learn from in order to help move from negative pathways back to positive ones.

Despite the additional freedom that students had to define pathways, their pathways did frequently begin and end with the emotions that appear at the start and end of the idealized pathways [5]. One departure from this generalization is in the pathways with a negative or slightly negative direction; it may be that our omission of "fear/despair" from the list of emotions was the cause, as those are the emotions that follow anxiety in the idealized pathway. In our next implementation of the survey, we plan to add the omitted words back in and examine how they affect students' pathways.

Our future work also includes the development of methods to more deeply analyze the middle of the pathways or examine the entirety of the pathway, including sub-progressions, mental blocks, and interruptions of negative feelings that can shift a negative pathway to a positive one. Identifying these shifts is key to discovering strategies for students to help themselves or instructors to help students get students on positive pathways that contribute to an improvement in global affect towards engineering. We also plan to undertake a comparison of the results from our survey analysis to interview data about emotional pathways, as a step towards validation of the instrument. Looking forward, the study of affective pathways may also have connections to and impacts on other important factors for retention and student experience such as engineering identity, self-efficacy, and mindset.

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