Assessment of a Survey Instrument for Measuring Affective Pathways

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Abstract
This research paper analyzes the emotions that students experience while completing ill-defined complex problems called Open-Ended Modeling Problems in their engineering courses. Students are asked to make their own modeling decisions, rather than being given those assumptions, as is the case in most textbook problems. There are many approaches they can take, and having to make decisions and assumptions that impact the problem has been found to generate strong emotions.

Goldin's research on mathematics education asserts that students tend toward affective pathways while completing problems. An affective pathway is the sequence of emotions that a student goes through while solving a problem. Goldin theorizes that there are two main categories of affective pathways that students fall into: positive pathways and negative pathways. This paper builds on our previous work on the development of a survey instrument to quantitatively measure affective pathways. The survey asked students to drag and drop emotions into the order they experienced them during their problem solving process.

In this study, we sought to improve upon our survey instrument. Based on our previous research, we added several emotions and alphabetized the list to see whether the order of words impacted the responses. Here, we examine the results from an updated survey question as well as a small set of interviews conducted to investigate how students approach answering the survey question by having them think aloud while completing it. The survey was sent to six classes at five universities, and interviews were conducted with six students at two of those universities.

Through our analysis, we found that most students feel confused or frustrated at some stage, and that their emotions change as they continue from start to finish, which is in line with the findings of the previous version of the survey instrument. We are looking further into whether the students turned their frustrations into the positive or negative pathways that Goldin describes. From the interviews, we found most of the verbalized pathways matched what was submitted through the survey instrument. However, there were instances where the submitted and verbalized pathway did not match, suggesting further changes to the question's implementation.

Developing a reliable method for measuring affective pathways will enable future study of why and when positive or negative pathways occur, as well as potential actions that engineering educators can take to help students interrupt negative pathways. Goldin's work suggests that negative pathways influence students' global affect, which could impact retention in engineering.
Keywords: affective pathway, global affect, local affect, emotion, survey

1 Introduction

While problem-solving is often thought of as a cognitive endeavor, the process also causes students to experience emotions [1], particularly when the problems are novel or challenging. Over the course of a problem, the series of emotions that a student experiences is referred to as an *affective pathway;* these pathways are intimately intertwined with the cognitive processes of

problem-solving [2]–[4]. This work focuses on the development of a survey question that our research team is developing to measure students' affective pathways.

Affective pathways are of significant interest to us as a result of their ability to influence students' *global affect* (attitudes, self-concept, beliefs, and values about the subject) as students trace and retrace affective pathways during disciplinary work such as problem-solving [2], [4]. Since a common goal for inclusivity, particularly early in the engineering curriculum, is retention of students who may feel less initial belonging or confidence within engineering, we believe that attending to and studying not only global affect itself, but also the influences of affective pathways on its development, is of importance to the field of engineering education. Understanding how negative local affect (which is often unavoidable during complex problem-solving [5]) can lead to either an overall negative affective pathway or a positive pathway has implications for both how students and perhaps even more importantly their instructors frame and react to student emotions during problem-solving.

Within the context of this larger research goal, we are seeking in this work to develop methods for measuring affective pathways during problem-solving as a first step towards understanding their influence on global affect. In our previous work [6], we reported on our initial development of a survey instrument to measure the emotions that students experience while solving a problem or completing a project. In this paper, we present our iteration on that survey instrument as we strive to capture students' experiences while solving a particular type of ill-defined problem termed an Open-Ended Modeling Problem, or OEMP for short [7]. Here, we present the results of iterations on our survey question and make additional recommendations on its revision based on two sets of data: (1) results collected from the distribution of two revisions of the survey instrument and (2) a small set of interviews in which students walked through the survey question while thinking aloud. The main research questions we consider are:

- RQ1: How have the changes to the list of emotions in the survey question affected patterns in responses?
- RQ2: Does the verbal affective pathway described in the interviews differ from the submitted survey response for that student?
- RQ3: What changes to the survey instrument are suggested by the results from the survey responses and interviews?

The answers to these questions provide insight into how sensitive the survey instrument is to changes in the list of words presented to students and they highlight positive and negative aspects of its ability to capture the complex emotions that students experience while problem-solving. Eventually, we hope that this instrument will enable both researchers and instructors to measure, at scale, the emotions that students experience while problem-solving, equipping them to make connections between students' affective pathways and other important factors such as learning, global affect, or affective regulation.

2 Background

Previous research done in mathematics education suggests that students experience certain sequences of emotions as they solve difficult math problems [2]–[4]. These sequences of emotions are called *affective pathways*. Affective pathways measure students' *local affect* about a field – the emotions that students go through as they solve problems. Goldin theorized that these pathways fall into two categories: positive affective pathways and negative affective

pathways, based on the overall connotation of the emotions listed in the pathways. From this theory, he developed two "idealized" pathways, which he thought represented the emotions that most people experience while solving difficult math problems. Goldin's positive and negative idealized pathways both start the same way, with *curiosity* leading to *puzzlement* and then *confusion*, and then the pathway splits into the positive and negative pathways. The positive pathway then goes into *encouragement*, followed by *pleasure*, *elation*, and *satisfaction*, and the negative pathway goes into *frustration*, followed by *anxiety* and *fear/despair*. Goldin also theorized that a student can move from *frustration* to *encouragement*, interrupting the negative pathway and moving to the positive pathway. Similar common sequences of affective states have also been associated with problem-solving or learning in other disciplines [8], [9].

Building on Goldin's work, a questionnaire developed by Gómez-Chacón was used to study interactions between cognition and affect [10]. The questionnaire included the following survey question (p. 210): "Which of the following routes best describes your emotional pathway when solving the problem? If you identify with neither, please describe your own pathway." The two affective pathways were one that enables problem solving, modeled on Goldin's idealized positive pathway ("curiosity → puzzlement → bewilderment → encouragement → pleasure → elation → satisfaction"), and one that constrains or hinders it, based on the idealized negative pathway ("curiosity → puzzlement → bewilderment → frustration → anxiety → fear/distress") [2], [10]. Thus, the answers to this survey question are interpreted as following the idealized positive or negative pathway or falling into a single third category of a "subject-formulated" pathway. Of 32 responses in that study, 15 selected the positive pathway, 4 selected the negative pathway, and 13 formulated their own pathways [10].

The significant number of people – about 41% – who formulated their own pathway in that study suggests to us that many people did not identify with the idealized pathways presented to them. This motivated our previous work [6], where we started developing a drag-and-drop survey instrument to measure students' affective pathways. Since we saw that so many people did not identify with the idealized pathways, we thought that having students fully make their own pathways would yield more accurate results.

In that study [6], we saw some similarities between Goldin's idealized pathways and the pathways that students described, especially between the starting and ending words. The starting words in both of Goldin's idealized pathways were *curiosity* and *puzzlement* [2], and the most common starting words selected by students using our survey instrument were *curiosity* and *confusion*. The ending words on Goldin's idealized positive pathway were *elation* and *satisfaction*, and our most common ending words for positive pathways were *satisfaction* and *accomplishment*. The ending words for Goldin's idealized negative pathways were *anxiety* and *fear/despair*, and our most common ending word for negative pathways was *confusion.* In our survey from Fall 2021, we found that the four most frequently used words were *confusion* (116), *accomplishment* (98), *curiosity* (90), and *frustration* (88). We classified students' submitted pathways as positive, slightly positive, neutral, slightly negative, or negative based on the valence of the emotions they used. The valence of each emotion is the positive, negative, or neutral connotation associated with each emotion. We found that the majority of students' pathways were positive (58), followed by neutral (39), slightly positive (34), negative (16), and slightly negative (14). Another way we classified pathways was by looking at the initial valence

compared to the final valence. We found that 49.1% of responses started with a negatively-valenced emotion, but 59% of responses ended with a positively-valenced emotion. This supports our findings that most of the responses were positive pathways.

3 Methods

In this study, we surveyed and interviewed students about their affective pathways under a protocol approved by the University at Buffalo Institutional Review Board. The invitation to participate was only extended to specific classes that used OEMPs in various formats (as in-class assignments, projects, homework assignments, etc.).

3.1 Survey

Students were invited to take a survey about OEMPs either via QR code displayed during class or a link sent out through their learning management system. The survey was distributed via Qualtrics and included a number of questions about students' experiences with OEMPs. In this work we are focused on a single question designed to measure students' affective pathways; the question as presented in Spring 2022 is shown in Figure 1.

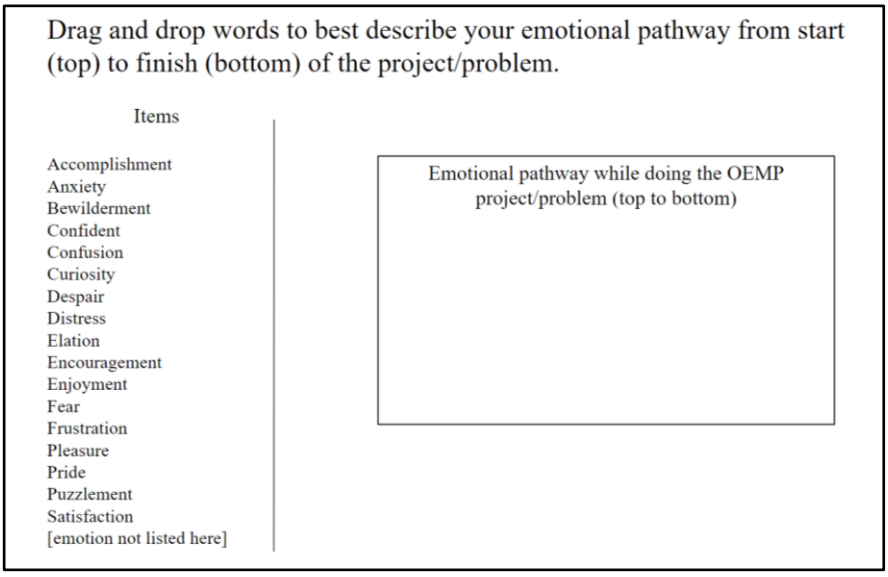

Figure 1: Survey question on Qualtrics given to students in Spring 2022

This paper examines two iterations on this survey instrument, which were distributed in Spring and Fall 2022. In the Fall 2021 iteration of our survey instrument [6], we had left out some of the words that are in Goldin's idealized pathways (*elation* and *fear/despair* - see Table 1 for the list). The first iteration discussed in this work (shown in Figure 1), distributed in Spring 2022, explicitly reintroduced those emotions to the list to assess the importance of their inclusion, and also added *confident* and *enjoyment* based on results from parallel work in which we analyzed interviews about the completion of OEMPs [5]. It also alphabetized the emotions in order to address concerns that students might be influenced by the order of presentation. After analyzing the data from the Spring 2022 semester, we discussed changing the question to optimize the user experience. Based on the data from those first two iterations, we decided on the additional changes shown in Table 1; reasoning for those changes is presented in the Discussion of this paper, following presentation of the results from our Spring 2022 iteration.

Table 1: Survey iterations

Semester	List of emotions
Fall 2021	Initial iteration [6] included the following list of emotions: *Confusion, Curiosity, Puzzlement, Bewilderment, Encouragement, Frustration, Pleasure, Anxiety, Pride, Accomplishment, Distress, Satisfaction, [emotion not listed here]*
Spring 2022	Modified Fall 2021 list with the following changes: ● Alphabetized the list ● Added: *Confident, Despair, Elation, Enjoyment, Fear*
Fall 2022	Modified Spring 2022 list with the following changes: ● Added: *Excitement, Happiness, Stress* ● Removed: *Bewilderment, Despair, Elation, Fear, Pleasure, [emotion not listed here]*

Table 2: Survey Population, Spring 2022

University Pseudonym	Class	# survey responses/# responses to pathways question/# in class
Red University	Advanced Aerospace Structures	22/19/50
Purple University	Dynamics	50/40/100
Purple University	Statics	19/15/80
Green University	Dynamics	6/6/13
Maroon University	Statics	19/19/32
Onyx University	Dynamics	50/49/79

Table 3: Survey Population, Fall 2022

University Pseudonym	Class	# survey responses/# responses to pathways question/# in class
Purple University	Dynamics	27/25/40
Purple University	Road Vehicle Dynamics	61/52/95
Purple University	Statics	64/62/158
Onyx University	Scientific Computing & Machine Learning	28/26/55

In total, there were 148 responses to our survey question in Spring 2022 and 165 responses in Fall 2022; Tables 2 and 3 summarize the population for the survey, which was distributed to undergraduate engineering classes at various institutions: Red, Purple, Green, Maroon, and Onyx University. Red, Purple, and Green Universities are all in the northeastern United States. Red University is a private research university (R2), and Purple (R1) and Green University (R2) are

both public research universities. Maroon University is a private liberal arts institution in the southern United States. Onyx University is a public research institution in the Midwest (R1).

3.2 Interviews

In Spring 2022, students in the Statics class at Maroon University and the Dynamics class at Purple University were also given the option of consenting to participate in an interview as well as the survey. Six students were randomly selected to complete an interview via Zoom. The interview protocol asked students to recall their problem-solving process as they completed the OEMPs. In one portion of the interview, students were asked to complete the affective pathways survey question on their computer while thinking aloud about the words they chose and the reasonings behind their choices.

3.3 Survey Analysis

Once all data was collected, a spreadsheet was formulated which contained the responses to the drag-and-drop pathways question, the number of times each emotion was used, and the number of times each emotion was used first. Our research team then found different ways to quantitatively analyze the data, such as finding how many times each word was used in the second to last and last position. We also looked for the existence of patterns in the pathways, and if so, what the patterns were. These patterns were then examined to check for similarities with the idealized positive and negative pathways [2].

Each of the emotions listed in the survey was assigned a valence of positive, negative, or neutral. These valences were assigned to be consistent with Goldin's work wherever possible [2]. Positive words include; *accomplishment, confident, elation, encouragement, enjoyment, excitement, happiness, pleasure, pride,* and *satisfaction*. The negative words include *anxiety, despair, distress, fear, frustration,* and *stress*. The words that our research team has determined to not invoke positive or negative feelings are categorized as neutral words. These words are *bewilderment, confusion, curiosity,* and *puzzlement*.

We analyzed the responses by noting whether the pathway contained positive, negative, or neutral emotions, and what the direction of the pathway was. The last two words in a pathway are key elements we analyzed in the data set. These are the words that determine the pathway direction (positive, slightly positive, neutral, slightly negative, or negative), but we also found trends in the last two word combinations. An example from the collected Fall 2022 data goes as follows: "Curiosity, Confusion, Anxiety, Confidence, Satisfaction." This pathway ends with *confidence* and *satisfaction*, both words with a positive valence, thus this pathway has a strongly positive direction. On the other hand, another response pulled from the Fall 2022 data only ends with a neutral and a positive word: "Distress, Encouragement, Confusion, Accomplishment," with *confusion* being the neutral word and *accomplishment* being the positive word, thus this pathway is slightly positive.

3.4 Interview Analysis

The interviews were transcribed by a member of the study team. For this study, we only analyzed the response to the single question in which the student was asked to complete the affective pathways survey instrument while thinking aloud. Three of the authors independently used the transcripts to reconstruct the pathway from what the participant said in the interview, without

looking at the survey response. The three authors then compared their theorized pathways and reached a consensus through discussion. This agreed-upon pathway that is constructed from the transcripts without looking at the survey response is termed the "verbal interview pathway". The verbal interview pathway was then compared to the pathway actually submitted by the student through Qualtrics during the interview, which we call the "submitted interview pathway."

4 Results

4.1 Survey Results

4.1.1 Frequency of Use

Figure 2 shows the percentage of students who used each emotion in their survey pathway. The most used words across all three semesters were *accomplishment*, *anxiety*, *confusion*, *curiosity*, *frustration*, *puzzlement*, and *satisfaction*. These were all found at ~40% or above. Confusion was the most frequently used across all three semesters. There is a large gap between anxiety (~40%) and the next most used words (*confident*, *encouragement*, and *enjoyment*), which were all used by ~30% of respondents. *Stress* was also used in about 50% of the Fall 2022 pathways (it was not previously included in the survey question), indicating that the addition of this word was beneficial in this semester. The low frequency of *bewilderment*, *despair*, *elation*, *fear*, and *pleasure* can be seen in the figure. The three least used words in the Spring 2022 semester (*elation*, *despair*, and *fear*) were all words that were added after the Fall 2021 survey. We then analyzed the next three least used words and found they were the same as the Fall 2021 (*pleasure*, *bewilderment*, and *pride*). Revisions to the survey due to these results are explained in the Discussion section.

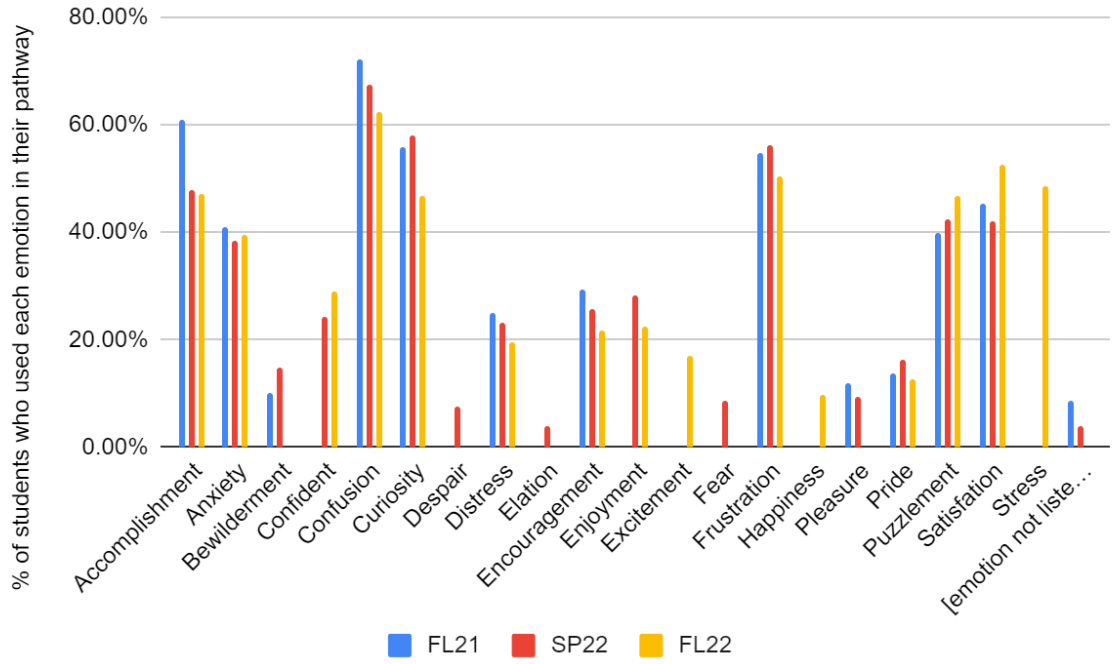

Figure 2: Combined column chart of word frequency from surveys for Fall 2021 (n = 161), Spring 2022 (n = 148), and Fall 2022 (n = 165). Results from Fall 2021 are reproduced from [6] for ease of comparison.

In addition to overall usage, we analyzed the words that students chose at the beginning and end of their pathways. In Spring 2022, the most common starting words for students' pathways were *curiosity* (41 uses), *confusion* (26) and *anxiety* (20); no other word started more than 10 students' pathways. In Fall 2022, the same three were still most common: *curiosity* and *confusion* tied (34 each), followed by *anxiety* (26); unlike the results from Fall 2022, though, newly added words were used with more frequency: *puzzlement* (16), *stress* (14), and *accomplishment* (12).

The most commonly used last emotions in a pathway in Spring 2022 (for pathways with at least two emotions selected) were *satisfaction* (36) and *accomplishment* (35). Following the same trend in Fall 2022, *satisfaction* (47) and *accomplishment* (30) were the most commonly used last emotions. Directing attention to the second to last word, there are four words throughout the Fall and Spring of 2022 that are commonly used in the second to last position. In Spring 2022, *frustration* (23), *accomplishment* (14), *satisfaction* (12), and *confusion* (12) were the most common words used in the second to last position. In Fall 2022, *satisfaction* (20), *accomplishment* (20), *frustration* (19), and *confusion* (13) were the most common.

Using these most common second to last words and the most common last words, our research team looked for trends of these word pairings at the end of pathways. These results are shown in Figure 3 for Spring and Fall 2022. When *satisfaction* was listed last, *accomplishment* came before it 25% (Spring 2022) and 23% (Fall 2022) of the time. The other notable trend is that in Spring 2022, *frustration* was frequently an emotion that preceded both uses of accomplishment (23%) and satisfaction (22%) as the final word, with those combinations being comparable, in frequency, to *satisfaction* and *accomplishment*.

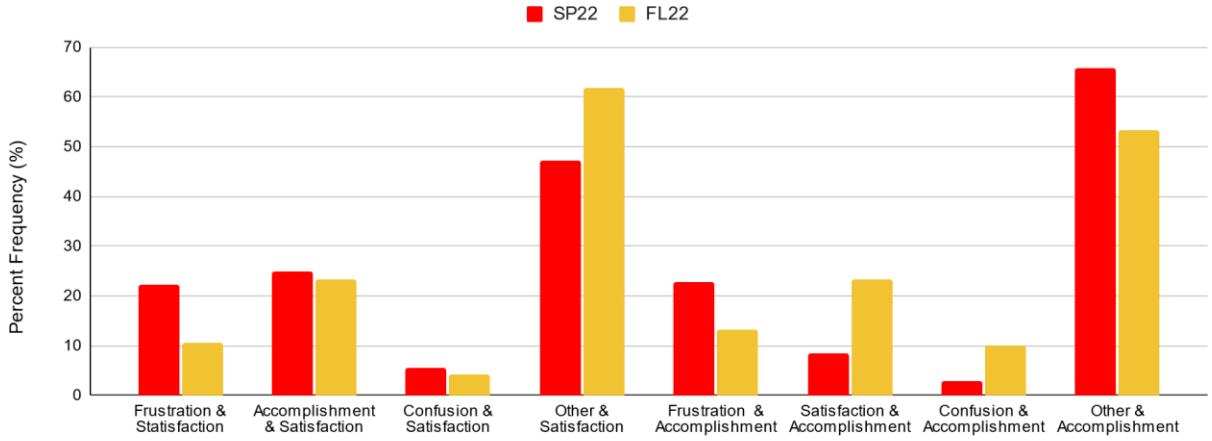

Figure 3: Percent frequency of word pairings at the end of pathways from Fall and Spring 2022, including the two most common final words: satisfaction (which ended 24% of pathways in Spring 2022 and 29% in Fall 2022) and accomplishment (which ended 24% of pathways in Spring 2022 and 18% of pathways in Fall 2022). Note that neither single-word pathways nor pathways ending in words other than *satisfaction* or *accomplishment* are included here.

4.1.2 Pathway Direction

Spring and Fall 2022 yielded similar results regarding the pathways that participants reported. Our research team found that the majority of students' pathways were either positive (2+) or

slightly positive (1+) in both Spring 2022 and Fall 2022. The full results can be found in Table 4. Table 5 breaks down these pathways further, examining the valence of *all* words in the pathway compared to its direction, which is determined only by how it ends.

Table 4: Pathway Directions

	Positive (2+)	Slightly Positive (1+)	Neutral (0)	Slightly Negative (1-)	Negative (2-)
Spring 2022 (n=144)	36.81%	27.08%	15.98%	14.58%	5.555%
Fall 2022 (n=165)	40.61%	27.27%	11.52%	5.455%	15.15%

Table 5: Pathways broken down by both direction (which depends only on the last two words) and valence of all words in the pathway.

Valence(s) present	Positive or Positive/Neutral		Negative or Negative/Neutral		Both Positive and Negative (and possibly neutral) words in pathway				Any	Total
Pathway Direction	Positive (2+)	Slightly Positive (1+)	Slightly Negative (1-)	Negative (2-)	Positive (2+)	Slightly Positive (1+)	Slightly Negative (1-)	Negative (2-)	Neutral (0+/-)	
Spring 2022	11.11%	4.17%	6.94%	2.78%	25.69%	22.92%	7.639%	2.78%	15.98%	100%
Fall 2022	13.33%	3.03%	1.82%	11.52%	27.27%	24.24%	3.64%	3.64%	11.53%	100%

In Table 4, 5.555% of the Fall 2022 pathways were strongly negative; from Table 5, 2.78% of pathways were negative and contained only words with a negative or neutral valence. This means half of the pathways that had a negative direction in Fall 2022 did not contain a single positive word. In a similar way in the Spring 2022 data, 15.15% of the pathways had a negative direction (Table 4), and 11.52% (Table 5), contained only negative or neutral words, so approximately three quarters of the negative pathways did not contain words other than those with a negative or neutral valence.

In contrast, looking at Table 4, out of all of the Spring 2022 responses, 38.61% had strongly positive directions. Table 5 shows that only 11.11% of positive (2+) pathways contained only positive and or neutral words. This means that over half of the participants that had a strongly positive pathway reported emotions of both positive and negative valences. In the Fall 2022, 40.61% of all the pathways were strongly positive and only 13.33% (Table 5) of positive (2+) pathways only contained positive or neutral words, indicating again that more than half of the participants created pathways with the presence of negative and positive emotions. Overall, the majority of pathways that have a negative direction have words with negative and neutral valence throughout and exclude those with a positive valence. We considered that this may point to a correlation between students who experience a range of emotions and them being more likely to create a positive pathway.

4.2 Interview Results

In Spring 2022, six students completed interviews, which are all included in our analysis. We focused on the part of the transcript where the students filled out the survey question and talked through their thought process. Table 6 shows the verbal interview pathways and the submitted interview pathways. Some students' verbal interview pathways differed greatly from their submitted interview pathways, while others had very similar verbal and submitted interview pathways. One student, Rebecca James, verbally described two emotions (*enjoyment* and *frustration*) as alternating back and forth in their pathway. This is because they said they felt like it was a puzzle that kept having to be adjusted. There was enjoyment in the process of tinkering with the problem, but it was also frustrating when it didn't work out.

Table 6: Verbal vs. submitted interview pathways. Words with no symbol appeared in both the verbal and submitted pathways. Symbols indicate the following: * = in verbal but not in submitted; ^ = in submitted but not in verbal; **bold** indicates verbal indication of looping/alternating; ( ) = submitted in follow-up "If you used [word not listed here], what word did you use?"

Pseudonym	Pathways
Jimmy	confusion, satisfaction, curiosity, enjoyment, distress, accomplishment, confident, pride
Katie Morano	distress, (overwhelmed), distress*, satisfaction, frustration, interest*, confusion, confident, accomplishment, felt good*, pride*
Rebecca James	elation, fun*, confusion^, **enjoyment, frustration**, accomplishment, fun*, curiosity^, puzzlement, encouragement^, satisfaction, confident*
Nontrad	confident, satisfaction
Luke Skywalker	confusion, curiosity, encouragement, enjoyment, satisfaction
Zach Noveda	(annoyance), puzzlement, frustration, (relief), encouragement^, confident, anxiety, (happy), encouragement*, (panic), playful*, enjoyment, fun*, accomplishment

All six interview pathways (verbal and submitted) were positive (2+). This was analyzed based on the procedure described in the Methods section. All six submitted interview pathways ended with one of the following emotions: *pride, accomplishment,* or *satisfaction*. The verbal pathways also ended in these words except for one, which ended in *confident*.

5 Discussion

RQ1: How have the changes to the list of emotions in the survey question affected patterns in responses? Despite changes to the survey question, the Spring and Fall 2022 data followed a similar trend to the Fall 2021 data in several ways: there were marked similarities in the most-used emotions, the overall breakdown of pathway directions, and even the patterns in the final two words (with *accomplishment* to *satisfaction* being the most common pairing). This reflects a similar pattern as Goldin's idealized positive pathway where *elation* leads to *satisfaction*, although students completing our survey were hesitant to describe their positive emotions with *elation*, tending instead towards *accomplishment*, *confidence*, etc.

The least commonly used words in Spring 2022 were *elation, despair,* and *fear;* all three of these words were new in the Spring 2022 version of the survey, which suggests that their omission in our first iteration in Fall 2021 likely did not affect those results very much. Excluding the newly

added words from Spring 2022, the least commonly used words were the same between Fall 2021 and Spring 2022: *pleasure, bewilderment,* and *pride*. We theorized that this was because *pleasure* and *enjoyment* are similar emotions, and *pride* and *accomplishment* are also similar emotions.

Iteration on our survey instrument to measure affective pathways has built our confidence in the instrument over time. After alphabetizing the words in Spring 2022, we were able to examine whether students were ordering their pathways intentionally or simply choosing words in the order presented. There were nine pathways in the Spring 2022 results that were in alphabetical order. All nine consisted of five words or less. The low number of responses with the words in alphabetical order suggests that students were truly thinking about the order as they dragged and dropped the words into the survey, not simply choosing emotions in their presented order.

Most of the students who responded to the survey (approximately 60%) included both negative and positive words in their pathways. Moreover, 38.81% of the pathways in Spring 2022 and 40.61% in Fall 2022 were positive in direction. However, the majority of students experienced emotions of both valences throughout their pathways. In future work, additional analysis methods for pathways should be considered: our analysis of the final two words to determine pathway direction as we had done previously [6] was intended to capture the overall experience, while still allowing for non-ideal pathways with ups and downs in valence; the analysis of whether pathways included all positive or negative words represents an attempt to extend this.

In the future, it will be beneficial to consider the experiences of students who use only words of one valence and intervene to better aid the engineering-solving process. Something of importance to consider in future work is how students are affected by experiencing pathways that have a negative direction and only contain negative and neutral words. A question that arose when reviewing this data is: does a student experiencing a fully negative experience deter them from wanting to solve future problems? When these students attempt new problems, will they start the problem with a tainted negative outlook that will hinder their abilities?

RQ2: Does the verbal affective pathway described in the interviews differ from the submitted survey response for that student? Most of the verbal pathways were similar if not identical to the submitted ones. The most striking difference between submitted and verbal responses was the inability to reuse words in the submitted one. One result of the interviews in Spring 2022 was that all six were positive (2+) pathways in both the verbal and submitted pathways. This might be due to the fact that the interviews were done on a volunteer basis, which can lead to bias. Students who had a positive experience with the OEMPs might be more likely to consent to an interview than students who did not. The same may be said for the surveys, as more were found to be positive than negative.

RQ3: What changes to the survey instrument are suggested by the results from the survey responses and interviews? As a matter of practicality, the research team felt that the list of emotions in the Spring 2022 iteration of the survey was too long, particularly since so many participants completed the survey on mobile devices. In general, the most used emotions were kept in the list and the least used were deleted (see Figure 2). Several low-use emotions (*Bewilderment, Despair, Elation, Fear, Pleasure*) as well as the option *[emotion not listed here]*

were removed from the Fall 2022 version of the survey instrument, since they were not used much in either Fall 2021 or Spring 2022. Despite its similarly-infrequent use in the survey results, *pride* was not eliminated from the word list for Fall 2022 for two reasons: (1) it was used by Goldin in his idealized pathways and (2) it was used in two of the six interviews from Spring 2022 (Table 6). We think this is important because the emotion was prominent in those individuals who used it during the interview, and has also spontaneously been used by students in previous studies of OEMPs [5].

We decided to add *happiness*, *stress*, and *excitement* to the list for Fall 2022 since they were used by multiple students during previous interviews about OEMPs [5]. We speculated that *elation* was one of the least used words because it is a strong emotion, and *happiness* is a more common day-to-day feeling. Emotions of *pleasure* might also fall under *happiness*, which could explain its relatively low usage frequency; this led us to decide that we should remove *pleasure* from the provided list of words. *Stress* was added to the list for Fall 2022 for a similar reason. We thought that students might be less likely to pick *distress*, a more extreme emotion. The word was also used in previous interviews [5], which show that students felt stressed but may not have expressed it via the survey because of the absence of it on the word list. Similar to our thoughts on *happiness*, we decided to add *excitement* because it is a more day-to-day feeling than *elation*. This theory proved to be right as the percentage of people who used *elation* in Spring 2022 was ~4% and the percentage of people who used *excitement* in Fall 2022 was ~17%.

In this study, the surveys were completely anonymous and participant demographic information was not collected. Depending on the future uses of this instrument, it will likely be important to collect participants' demographic information. In the future, we also suggest two additional changes: first, we plan to add the word *uncertainty* to future iterations of the survey word list. In our current reviews of literature, it has appeared frequently as an emotion students have while engaged in learning: results suggest it is felt during engineering design [11] and may trigger additional feelings of curiosity, anxiety, or anger [9]. Second, we would like to change the format of the question. In all versions of the survey discussed here, the survey instrument was formatted as a drag-and-drop question, with the word bank on the left and a space to drag the words on the right. One advantage of this format was that it made sense visually; once the words were dragged to the right, they were displayed from top to bottom to mirror the respondent's emotional pathway from start to finish. One of the major drawbacks of this format was that it did not allow for words to be used more than once. This poses an issue, because in some of the interviews, students went through some emotions more than once over the course of their pathway, but the drag-and-drop question format did not allow students to reflect this in their responses. Preventing students from reusing an emotion may therefore threaten the instrument's validity.

6 Conclusions

We were motivated to develop a quantitative survey measure for affective pathways due to the strong links between emotion and cognition during learning and problem-solving [2], [9], [12] and the potential for local affective experiences to alter students' global affect about engineering [2], [3]. Unlike instruments for measuring achievement emotions, e.g. [13], our work seeks to explore the specific order of emotions through a single problem. We thought that having students create their own pathways rather than selecting from only two options as in [10] would allow us

to more easily see where students might be reaching a mental block in their pathways, so we might be able to interrupt negative pathways sooner; this is important as negative pathways can eventually lead to disengagement with the learning goals of the activity [2], [8]. Additionally, repeated experiences of negative pathways likely create negative global affect towards engineering, which could lead students to leave engineering.

While data in this study was not collected in an identifiable manner, we believe that in future work it will be particularly important to understand the experiences of the small subset of students who experience negative pathways with no positive emotions at all along their pathways. This would help us understand if these students were struggling within the course, and whether their negative experiences throughout the whole process could lead to ineffective learning experiences. Then our research team could see if there was a possibility for this negative experience to be interrupted with an intervention. If this was effective our hope would be to normalize this outside intervention as a standard practice in engineering education.

In an effort to keep the benefits and potentially eliminate the drawbacks of the drag-and-drop question format, we want to change the format of the survey instrument to a series of drop down menus for future implementations. There will be multiple drop down menus in a row, all with the same bank of words as options. This format allows respondents to use the provided words more than once, while still keeping the same visual aspect of the words going from top to bottom to mirror a pathway from start to finish.

Validation of any instrument can be achieved only insofar as evidence can be gathered to support the specific end uses or claims of the instrument that are clearly articulated [14], [15]. In this work so far, we have gathered evidence related to the claim that our drag-and-drop survey instrument measures affective pathways during complex problem-solving. The evidence collected to this point is based on two main areas: content-oriented evidence and response process evidence. The content of the survey question is relevant to measuring affective pathways during problem-solving, due to its correspondence with past work in that area [2], [5], [8], [10], [12]; we see notable similarities between student responses to our survey question and affective pathways described in the literature that make us confident that students are recollecting their emotional experiences during the completion of OEMPs. In this work, the think-aloud interviews also give us our first response process evidence for the question.

Having a reliable instrument for measuring affective pathways is a necessary step towards not merely understanding students' experiences (which may be of use to instructors who are implementing novel problems in their classes for understanding where additional scaffolding is needed), but also for connecting those experiences to a variety of other important factors that influence or are influenced by local affect. In the future, we hope others and ourselves will extend the use of this instrument to connect information about students' affective pathways to other important aspects of affect, including student and instructor strategies for regulating affect and other meta-affective strategies that can influence students' local affective experiences [3], [10]. The application of this survey instrument to answering those questions along with other questions will need to undergo further validation, since factors as simple as question order or survey length can interfere with validity [15].

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