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Exploring Emotional Trajectories of Engineering Students: A Narrative Research Approach*

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As the problems that engineers are framing and solving are becoming more complex, it is becoming critical to develop a more nuanced understanding of learning that encompasses more than separate knowing and includes connected knowing. To better understand connected knowing within engineering students, we explore the role of emotion in engineering education. In particular, we attend to the primary research question, how do emotions underpin the narratives of engineering students? This narrative research project involved conducting interviews with 21 undergraduate engineering students from year one to five in their engineering program and from a diversity of engineering disciplines. Our findings suggest a trajectory of emotions including enjoyment of pre-engineering activities, nervousness about core classes, frustration and discouragement with core classes, and finally an overall satisfaction with the educational experience. Two constructed narratives are included to provide the reader with an individualized, contextual, and complex view of the lived reality of emotional trajectories. As engineering educators, the emotions of our engineering students may prove critical as we are preparing engineering graduates to make decisions and to contribute to some of the world's most pressing problems.

Keywords: narrative research; connected ways of knowing; emotions; identity formation

1. Introduction

The engineering education research community is beginning to expand conceptions of learning to be a more complex process than previously understood. However, many engineering educators believe learning and cognition to be separate from emotion and affect [1–3]. Engineering faculty and professionals tend to favor conceptions of engineers as rational decision makers and problem solvers over conceptions of engineers as people who use their feelings and emotions to make decisions and solve problems. In fact, Woods, Briedis, and Perna [4] surveyed 104 various professionals, soliciting their opinions on what skills are essential for students moving into the engineering profession. Skills associated with feelings and emotions, such as empathy, self-awareness, and management of emotions, ranked lower than skills generally associated with cognition and performance, such as problem solving, decision-making, and critical thinking.

Consequently, engineering faculty have favored focusing educational endeavors on students acquiring separate knowing, which conceptualizes knowing as being analytical, objective, detached, and adversarial over connected knowing, which conceptualizes knowing as involving perspective taking, empathizing, and feeling [5]. In other words, in connected knowing, "Emotion is not outlawed, as in separate knowing. But reason is also present. The self is not obliterated. You use your own experience as a means of understanding what produced the idea you are attempting to understand" [5].

In engineering education, curricula is traditionally made up of engineering science, mathematics, and science classes in addition to required general education courses. In recent years, many programs have begun to include engineering design courses, typically in a first year course and in a capstone design experience [6]. In the traditional engineering science, mathematics, and science courses teachers value separate knowing as the courses are comprised of formulas, equations, and over-simplified problems. In engineering design courses, there is an opportunity for a focus on connected knowing as students are typically challenged to engage in a design project for a particular stakeholder. However, many design courses focus on technical only

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solutions and do not consider socio-technical solutions to be within the purvue of engineering. An example of this occurred in a program that I, the first author, was teaching in, when a team of environmental engineering students was challenged with designing a damn. The students began their assessment through developing an understanding of how the damn would impact the local ecosystem (e.g., fish in the river; birds that nested on the river banks), the ways it would impact the way that people moved from one place to another, and the ways that it would impact people whose properties and homes would be under water after the damn was put into place. In a project update, the professor told the students that, as engineers, they only needed to concern themselves with the technical aspects of designing the bridge. This transitioned the focus of the design course to one that values separate knowing at the expense of connected knowing.

Additionally, there are some innovative engineering education programs that are integrating design throughout the curriculum [7–11]. However, even in these cases, the engineering sciences are often valued higher than the design courses by faculty and many students, thus valuing separate knowing over connected knowing. Downey and Lucena describe this devaluing of engineering design, placing science-based problem solving above engineering design, as something that is learned by students through experiencing science-based engineering curricula [12]. "Thus locating design downstream of science-based problem solving can produce a hierarchy that may be reproduced regularly and routinely in the traditional curriculum . . . Students may come to know that the engineering sciences are fundamental and that design is both subordinate and dependent" [12, p. 171]. For this reason, even students who come into engineering programs valuing connected learning, may learn to place higher value on separate learning.

In engineering education, valuing separate knowing over connected knowing has many impacts on our current engineering curricula, including impacts on the number and types of engineering science and design courses, impacts on the value assigned to these classes by students and faculty, and impacts on pedagogy. As the role that engineers are playing in society is changing and the problems that engineers are facing are becoming more complex, socio-technical problems, it is critical that we develop a more complex understanding of learning. A form of learning is needed that encompasses more than the rational, analytical propositional knowledge acquisition, separate knowing, and begins to encompass the emotional side of learning, connected knowing. In Fig. 1, we provide an illustration of separate and connected learning, and alignment of these types of learning with engineering coursework. As can be seen in this figure, due to the curriculum encompassing separate and connected knowing, engineering education is an appropriate context to develop an understanding of separate and connected knowing, and, in particular, developing an understanding of the role of emotions in engineering student learning.

In this paper, we are interested in developing a deeper understanding of connected knowing. However, prior to developing an understanding of connected knowing, we feel it is important to develop a baseline understanding of emotions that students experience in engineering programs. In developing a nuanced understanding of emotions that students experience, we can then begin to see ways in which students and faculty value separate and connected knowing within their programs. While understanding the emotional development of students is relevant to all disciplines, it is especially important in engineering education as we prepare engineering graduates to tackle society's grand challenges [13]. The facilitation and regulation of emotions have been connected with many concepts important to engineering education such as decision making, creativity, collaborative learning, and lifelong learning [14–16]. Moreover, in developing an understanding of the overarching emotions throughout an engineering degree, we may begin to shed light on issues of persistence and identity development. In this study we will focus on students who have persisted in their engineering degree program, and through tracking their emotional trajectory we uncover coping skills, characteristics such as doggedness, and the importance of social networks, such as family support.

It is difficult to describe or define "emotion" per se. Emotions are connected to many other psychological factors, and are often the result of events that occur in a student's life, whether they have already occurred, are occurring, or are projected to occur in the future. Emotions are also largely dictated by student attitude, which is a student's disposition toward a certain activity or idea [17]. So, what is an

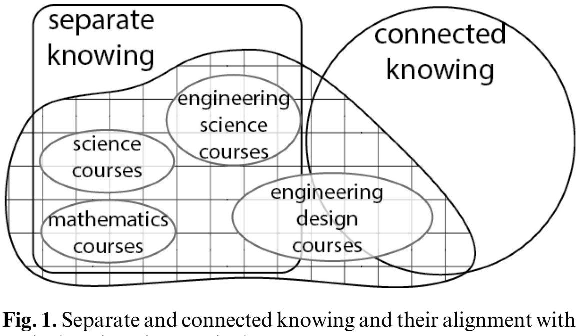

Fig. 1. Separate and connected knowing and their alignment with typical engineering curricula.

emotion when it is separated from these factors? Pekrun [18] suggests that this question is misguided, and that emotion is actually a confluence of all of these factors, impossible to be stripped down to a thing in itself. An emotion is the temporary mood that emerges from ''affective, cognitive, physiological, motivational, and expressive components'' [19, p. 4]. It is the way that a person feels while directing the self toward a particular phenomena, expressed in states such as happy, sad, anxious, etc. While emotions are defined as temporary states directed at particular phenomena, mood is a less intense but more long term kind of emotion. Mood encompasses the student's disposition or attitude in general, not necessarily directed at any one phenomena [20]. Finally, the term ''affect'' refers to both emotions and mood [19]. Affect can be positive or negative on student performance, depending on what emotions students feel toward certain events and what moods the student embraces.

Emotions play a critical and complex role in learning, and this connection between emotions and learning has been widely confirmed in disciplines ranging from neuroscience to psychology. Immordino-Yang and Damasio argue that motivation to make ethical and beneficial decisions stems from one's emotional state [21]. They describe individuals that suffered damage to their ventromedial prefrontal cortexes, an area of the brain associated with emotional output. While these individuals experienced no apparent loss in cognitive ability or logical thinking, they would regularly engage in poor decision making. Immordino-Yang and Damasio argue that this is because, ''the emotions and social considerations that underlie good reasoning were compromised'' [21, p. 5]. Additionally, these individuals lack the ability to learn from poor decision making because there are no emotional repercussions or even emotional investments related to the decision making process. This example demonstrates that separate knowing alone is not sufficient for decision making, connected knowing is also required. In engineering education, as we focus our efforts on separate knowing, we are graduating engineers who are not prepared by our curricula to engage in decision making.

Few studies have focused on the role of emotions in engineering learning. Those that do focus on emotion structure their studies on affective experiences in a given year or short time period [22–24]. There is a need to look at emotions from a more holistic perspective to provide a deeper understanding of emotions that are present throughout engineering college programs, the implications of these emotions on student learning, and the implications of these emotions on professional identity formation. A deeper understanding of the integral role of emotion within engineering education promises to have implications for developing engineering students' connected knowing. Connected knowing encompasses critical thinking, sound decision-making, motivation, and life-long learning. In addition, connected knowing encourages us to overcome the problematic separation between separate knowing and connected knowing. We argue that both separate and connected knowing are integral aspects to holistically understand engineering student learning.

In this exploratory qualitative study, we will initiate a look at the emotions present as students progress through their engineering programs. We will begin with a discussion of the theoretical framework used in this study, that classifies emotions as high or low activation and positive or negative valence. Next, we will discuss the research design used in this project, this includes a thematic analysis of interview data, the development of a theory from this analysis, and the construction of two narratives to demonstrate the complexity and nuance inherent in students stories. In conclusion, we will discuss implications of this work for practicing engineering educators.

2. Theoretical framework

While there is no agreement over the classification of emotions, a common classification takes into account the intersection of activation and valence (see Fig. 2) [25, 26]. Emotions can range from low to high activation [27, 28]. Low activation emotions are low energy emotions such as boredom, hopelessness, or relief. High activation emotions are higher energy emotions such as anger, anxiety, enjoyment, and hope. Another classification of emotions in this model includes the valence of emotions, positive or negative. Positive emotions include enjoyment, hope, pride, and relief, while negative emotions include anger, anxiety, shame, boredom, and hopelessness.

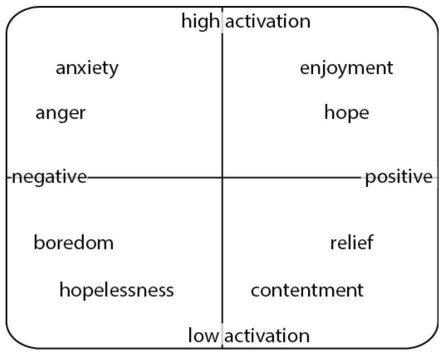

Fig. 2. Illustration of emotions classified at the intersection of activation and valence.

Table 1. Examples of ways that different types of emotions can impact learning

Emotion type	Learning implications	Examples of learning and thinking strategies
High activation emotions	Flexible and higher order learning strategies	Metacognitive, elaborative, organizational, and critical thinking
Low activation emotions	Less flexible learning strategies	Memorization strategies and rehearsal
Negative emotions	External regulation of learning	Learning to pass a test
Positive emotions	Self-regulated learning	Learning to understand and master the material

Research shows that the activation and valence of emotions have implications for learning (see Table 1). High activation emotions are associated with flexible and higher order learning strategies such as metacognitive, elaborative, organizational, and critical thinking while low activation emotions are tied to less flexible learning strategies, such as memorization strategies and rehearsal [29]. Moreover, negative emotions are associated with external regulation of learning while positive emotions are associated with self-regulated learning. In this paper, this classification system of emotions will be used to help develop a deeper understanding how emotions underpin engineering students' experiences.

3. Study design

In this research project, we took a social-constructivist perspective, which aligns well with the overall premise of this paper, that realities and identities are constructed as individuals live through and attribute meaning to critical events in their lives. As can be seen in the following design of this research project, the researchers and participants first co-construct a reality during the narrative interview. Later, during the multiple passes of analysis, the researcher constructs a reality that emerges from that interview (see communicative validation in [30]). In constructing and sharing complete narratives of two participants, we give voice to the participants. By giving the participant a voice in the dissemination of this research, we are demonstrating that we believe that the participant's voice and perspective is also valuable to understanding the complex process of learning. We concede that our voice is only one truth or perspective of the truth and that the participant's voice is equally valuable and their truth should be shared and will bring a deeper understanding to the reader. Additionally, by sharing these constructed narratives, the readers of the paper can develop their own truth or perspective based on the data. Throughout the process of this research project, the social-constructivist perspective informed our decisions and influenced the process. In this study we explore the role of emotion in engineering education. In particular, we attend to the research question, *How do emotions underpin the narratives of engineering students?*

3.1 Setting and participants

The setting for this study was a college of engineering located at a southeast public land grant university in the United States of America. The participants in the research project included engineering undergraduate students who had been in the program for one to five years and from any of the engineering disciplines offered in the college of engineering. To recruit students for narrative interviews, flyers were distributed throughout the engineering building and a call for participation in the research study was included in the engineering college's weekly electronic newsletter. Interested students completed a demographics survey, which was used to monitor the extent to which the volunteer sample was representative of the diversity of the engineering college. Each participant received an incentive of a $30 gift card at the end of the interview. The 37 undergraduate students who completed the survey were contacted over a two-week period by email, with 21 students responding to the request and agreeing to participate in the one-hour audio- and video-recorded interview process. Seven women and fourteen men, representing five nationalities or ethnicities (White, Black, Asian, Native Hawaiian, and Hispanic) and eight engineering disciplines (mechanical, electrical, civil, biochemical, biological, environmental, computer systems, and agricultural engineering) participated in the study. Participants also represented every academic year in the engineering program from year one to five.

3.2 Research quality

To ensure high quality data collection and analysis, the leadership team piloted data collection methods for one year prior to the beginning of the data collection phase of this project. During this pilot phase, we engaged in both multiple and single person interviews and different types of interviewing techniques, including critical events, narrative interviews, and photo elicitation. The researchers initially planned to use a constant comparative method to analyze the transcript data. However, after the first iteration of coding the data as emotions and triggers in NVivo, we noticed that the students described their emotions as critical learning events through storytelling. The constant comparative method would have resulted in a loss of the richness of the data, thus, we opted for a narrative research design and used individual narrative interviews during data collection to attain a deeper, more complex, and nuanced understanding of the role of emotions in engineering education.

Throughout the process of conducting interviews, a continuous improvement process was employed [30]. After each interview, the interviewer reflected in a log trail, focusing on the process of conducting the narrative interview and recommendations to improve future iterations. We revised the interview protocol based on recommendations to ensure stronger narrative interviews. In weekly meetings, we discussed strategies for improving the quality of future interviews. This continuous improvement process helped ensure the potential credibility and dependability of the findings (see [31] for a more detailed discussion of this process). Other techniques used for research quality emerged from data collection methods and analysis are described below.

3.3 Data collection

Data for this inquiry were collected primarily through in-depth narrative interviews, each lasting between thirty minutes and two hours. Open-ended interview questions encouraged participants to reflect upon both their experiences prior to entering engineering as well as their stories as engineering students since majoring in engineering. Follow up prompts and probing questions were used to elicit more elaborate descriptions and clarifications of the narratives [32].

Narrative interview is distinguished from a traditional interview in so far as the goal is to elicit experiential narratives from the participant rather than to engage the participant in conversation. In other words, the participant must feel open to taking longer turns to develop their narratives [32]. Throughout the interview, researchers and participants work together to create narratives. The process of constructing a narrative during the interview is contrary to the idea of simply uncovering stories after an interview is complete. In narrative interviewing it is critical to follow "participants down their trails" [32] and to provide a space for the participant to feel comfortable taking long turns and sharing their narrative without interruption. The interviewer must allow the participant to tell his or her own story, even though it may not follow an expected trajectory.

The first two interviews were conducted using a semi-structured protocol that included 13 questions. Utilizing the continuous improvement process described in the previous section, we determined that the semi-structured format was preventing the interviewers from getting rich descriptions of the students' experiences as the questions limited participants from constructing their narratives within the interview. The interview style was revised and replaced with an unstructured protocol developed from a phenomenological approach advocated by deMarrais [33]. The final protocol, outlined below, included only one primary question with a series of probing questions to help develop a more complete and robust story of the participant. Through this process of developing the narrative interview protocol we also learned that it was helpful to directly inform students that the purpose of the interview was to construct a detailed narrative.

> I understand that you are a [#] year [type of engineering] student. Could you tell me your story and how you got to where you are today?
>
> Probing questions:
>
> - You mentioned ________ , tell me more about that.
> - You mentioned ________ , can you give me an example of that?
> - You mentioned ________ , how did you experience this moment?

3.4 Data analysis

We used narrative analysis methods in this research project because other methods simply fell short of capturing the complexities of the stories of engineering students and how their self-perceptions changed over time. During the analysis, we had many intermediate levels of analysis. For example, immediately following the interview, the interviewer wrote an abstracted narrative of that participant's story and shared that with the research team.

We contracted for external transcription and then conferred the accuracy of the transcriptions by listening to the audio recordings while reviewing the transcripts. In this manner, we attended to research quality by rigorously combing through the transcripts, looking for inconsistencies and errors while listening to the audio recordings, becoming better acquainted with the data in the process. Repeated listening of the audio tracks not only allowed us to ensure that the interviews accurately transposed from one medium to another but also allowed us to steep ourselves in the data.

After the narrative interviews were transcribed, we analyzed the transcriptions and audio files using a narrative research approach, thus employing narrative analysis [32, 34]. We began with the transcriptions of the participants and coded themes associated with emotions. These emotions helped identify critical learning events in the student narratives and helped us begin to become familiar with the types of emotions that are present in student narratives. After this thematic analysis of all of the narratives, a pattern of emotions common in the narratives of engineering students emerged as an emotional trajectory.

Meanwhile, we constructed narratives to uncover the lived experiences of engineering students and to demonstrate the complexities and subtleties that are inherent to each individual participant's narrative. To construct these narratives, we first identified excerpts around each emotion that was coded in the transcript to give context to the situation the student was describing. We then separated these excerpts from the transcript and arranged them temporally. We deleted any excerpts that were not relevant to the student considering a major in engineering, deciding to become an engineer, or describing their experiences as an engineering student (in school, work, or extracurricular activities). In addition, we deleted redundant excerpts and, sometimes, combined redundant excerpts for the final constructed narrative. Finally, we smoothed the narrative through deleting extra words and adding connecting words to help the narrative flow more smoothly, to provide details of the setting, or to offer more clarity to the story. We italicized any words that were added so that the reader can identify text that came directly from the transcript. This narrative analysis was important to develop holistic accounts out of individual events, bringing order and meaning to the data and events [32, 34].

The purpose of our narrative analysis is not to map to or 'prove' the trajectory model developed in the intermediate analysis but rather demonstrate how this plays out in the complexities, tensions, and idiosyncrasies of several students' lived experiences. As a research outcome, these narratives provide the reader with an individualized, contextual, and complex view of the lived reality of emotional trajectories. This provides a multi-faceted way of understanding the complex story of students' emotions and identity development.

The narrative approach taken in this research study is consistent with Op't Eynde and Turner's [35] argument in which they described a need to study the student within the context of a classroom and to take the perspective of the student when exploring emotions in education. They argue that the researcher's observation of their activities or environment are not as important as the student's interpretation of their environment and experiences. Schutz and Decuir also argue that emotions should be studied from a holistic perspective and within the appropriate context [36]. Narrative analysis is a well-suited approach to meet these challenges.

3.5 Limitations

In this study, there were some limitations that we will briefly describe here. The participants from this study were at a single institution and the context of this institution likely impacted the student's stories and experiences being an engineering student. While this is an institution at the highest research activity according to the Carnegie Classification system, the engineering program historically was a small program and had recently become a college of engineering, offering more options for undergraduate engineering degrees. In addition, while we analyzed a larger set of data, we were only able to include the constructed narratives of two engineering students. Although we would have preferred to include more constructed narratives in this publication, in the end we chose to provide more detailed narratives of our participants, even though that meant only sharing two of their stories. Another limitation of this study is that the later phases in the trajectory represent students' experiences who had persisted in engineering. Students who did not persist in the engineering program would have never reached these later phases in the trajectory and would have never been interviewed for our study due to our participant selection procedures. Finally, while we would have preferred to have the participants read over their narratives and check for clarity and correctness, we were unable to do this because of the extended length of time between the interviews being conducted and this manuscript being finalized.

4. Findings and discussion

During the intermediate thematic analysis of narratives, we looked across students' stories and abstracted an emotional trajectory (see Fig. 3). This emotional trajectory visually shows the phases of emotions as a pattern across student experiences as they were on their journey to become an engineer. In this phase of the research, two members of the research team iteratively read through the transcripts and coded themes related to emotions. The emotion codes were kept intact for each student's narrative, and put into a temporal order so that the patterns of emotions could be easily compared across the narratives. A pattern emerged from this intermediate level of analysis and the trajectory provided in Fig. 3 demonstrates the

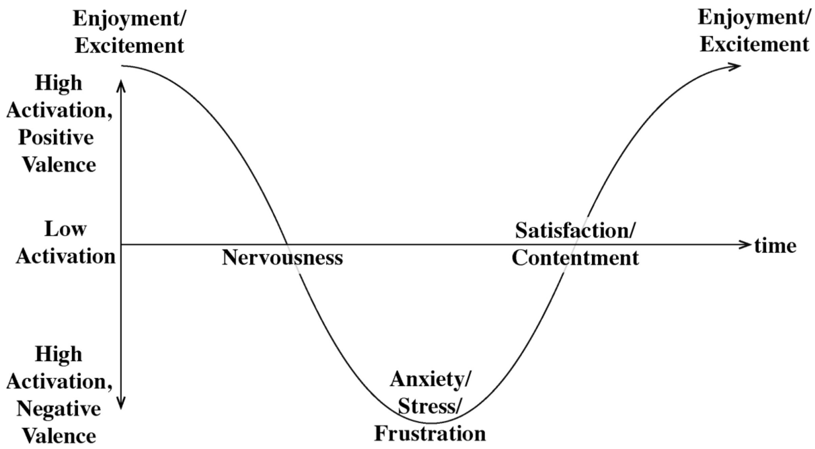

Fig. 3. Engineering students' trajectory of emotions and strategies during their academic journey.

pattern of emotions that were common across many of the narratives. This trajectory also shows how the valence and activation of emotions changes throughout the undergraduate engineering program.

The trajectory illustrated in Fig. 3 is not intended to imply a temporally linked linear developmental trajectory that students follow in a sequential manner as the narratives demonstrated fluidity between phases. Students might loop between frustration and satisfaction repeatedly as they progressed through their programs or they might skip the nervousness phase all together. Regardless of time spent circling in and out of these phases, most of the narratives demonstrated a trajectory that eventually took on the shape represented in Fig. 3 as students moved past frustration and doubt phases towards contentment or satisfaction. Many seniors expressed enjoyment and excitement as they began considering their first jobs as engineers. There were a few examples of narratives that did not reach the final phase of contentment or satisfaction. These individuals were first or second year students and are likely to reach this final phase with more time in the program. In an analysis of this common data set for a separate project, where we used structural analysis, similar patterns emerged in the data, thus further crystallizing these findings [37, 38].

As described above, we constructed two narratives that convey the range and trajectory of emotions. We included both of these constructed narratives below, and following each narrative we included an analysis of the narrative. These narratives were selected in order to be responsive to the multiplicity of experiences. Selecting two complete narratives as opposed to a compilation of several participants allowed for transparency in how the trajectory underpins the lived experiences of the undergraduate students. We selected the first narrative, Jake's story, because it fit well with the trajectory and had many similarities to other narratives in the data set. At the time of the interview, Jake was a fourth year agricultural engineering major with an emphasis in structural engineering. Later in his narrative he describes himself as a structural engineer, although his actual degree is in agricultural engineering. At this university, agricultural engineering was a general engineering degree in which students could choose an area of emphasis. We selected the second narrative, Libby's story, because it represented a story that was more of an outlier. Libby was a third year biological engineering major who was enrolled in the pre-medical educational track (referred to as pre-med in the remaining paper). Her story was different from others as she did not consider engineering at an early age, she considered engineering her senior year of college.

To provide some context, these students discuss earning grades of A's or B's. Typically, in the US, grades consist of five letter grades of A, B, C, D, and F. A is the highest score and commonly includes percentage scores of 90% or higher. F is the lowest score and commonly includes percentage scores of 59% or lower.

4.1 Jake's Narrative and Analysis

Growing up I always had a knack for figuring things out or fixing things. It was always simple things like Legos, or Lincoln Logs, or anything like that. An uncle of mine is an engineer, on my dad's side of the family. My granddad always told me, "Oh, you're going to be just like him, you're going to be an engineer."

We were always in the shop, always building. When we went to the house, besides fishing or hunting, we were in the shop building something. I always had the smaller *job*, tinkering, just grab two blocks of wood and see what you could build. Then, my other granddad got me into Legos and K'NEX and stuff like that. My dad and mom both said you could sit me down in a room with anything, a remote control, and I'd take it all apart and put it back together just to see. I always figured that aspect of it. I was always a problem solver. *If* something is broken, let's fix it. I always enjoyed that. I think a huge part of engineering is just being a problem solver.

I never put any thought to *what I wanted to be* until senior year *of high school*. I was good at two things, science and math. I *decided* to do structural *engineering* just because that was what *my uncle* did and what I was used to, building things and tinkering. I figured that I was more geared toward it.

So that's how I ended up here. I guess looking back, that first introduction class was a big pool. It was, yeah, this is cool, you decided what you want to do and I think you're going to like it. *But then* I took MATLAB that year. MATLAB was just not my thing. I just was real quiet, sat in the back. Really, I just went through and did what I had to do to get out and didn't enjoy it that much. I *still* feel like I *will* never use it. I haven't ever heard of anyone using it. Even when I did the job experience, we never did anything like that. It was all hand calculations. MATLAB really was, well, at least now I know I don't want to do any coding. I feel like some of the classes are there to tell you what you don't want to do and some of them are *to show you what you do want to do.*

Other early classes caused more stress. I hated calculus. Physics was awful, too. I actually got to a point in physics I was doing *so* horribl*y* I was like, "I can't do physics, I can't do calc. I can't be an engineer. The only class I'm making an A in is the engineering psychology class." *Everyone said*, "Oh, this is an easy freshman class." I was like, "If this is an easy class and I'm barely getting an A in it, I can't go to college." All these thoughts go through your head when you're freaking out.

I think my biggest thing coming in was I didn't know how to study. I mean, I always made A's in everything, it came so easy. I just didn't know how to study.

So I talked to my mom on the phone and she was like, "You've never given up on anything. Don't give up." I was like, "I'm not giving up, I just can't do it." She's like, "I don't want to hear that. I'm not listening to I can't." That was huge. I'll never forget that.

Then one day, it dawned on me. It was like, "I got through. I'm fine. I got what I needed to do and I'm okay." Now it's like, "Oh, I've got a test on Thursday? I'll go study, I'll be fine, regardless of what happens." I mean, if it goes wrong you can always recover. Even now, I still strive to do well, but *early on* it was so much piled on you with one grade could change your *scholarship* average by an entire letter grade. Now, I've got so many hours that it's just like, I got all A's last semester *and my GPA goes up* 0.001.

Freshman year was really rough, but I mean, once you get through it it's fine. I think you just have to put in the work, number one, and number two, you have to keep your head straight. No matter how much you freak out, you can't give up.

I think after I started settling down and started getting used to studying, I started using more resources that were there I just didn't know about, *like* office hours for professors. I never went the first couple classes or semesters. Never went, never knew anything about . . . I mean, I knew people went, but I was like, "I'm not going to go sit in my professor's office for two hours. I've got stuff to do." *I didn't realize* you get tips from *them*: For this class you should study like this. At that point, *I* realized, they teach this class; they teach the material; they make the test; they obviously know how you need to study for it. Once that clicked it was like, I know I can go talk to them, I know I can study, and I know it will help me.

I feel the professors here are a lot more personable *than in other departments*, a lot more helpful. It really motivates you. Even if you don't like a class, if you can go sit down with a professor and learn more about it, then you start *thinking*, this is cool, I see how *it works*. I mean, I think the biggest part of frustration comes from *when* people say, "I hate that class." But they don't really hate the class, they just hate it because they don't know what they're doing. When you look at a class and go, "I hate this class", nine times out of ten I feel like you're going to do worse just because you're not motivated. When you like a class you do a lot better.

The biggest eye opener and greatest experience I've had here as an engineer *was the* co-op I did my sophomore year. I love talking about it, honestly. It's been the best thing I could have ever done. It was full-time for two semesters. I got to do so many things. I was nervous going in because I was like, "I'm a structural engineer. This is process and mechanical. I don't know if I can help you." I ended up doing a lot of process engineering, a lot of mechanical, a lot of pumps and piping, and even a lot of electrical work. I really do feel like I'm a completely different person after that. I was more involved; I was more socially outgoing. I think I grew up a lot. Just learning *and* doing new things, but mostly just in the sense of being a working person. Yeah, you'll learn all the math and science here, but you have no clue of interaction with coworkers.

> The biggest thing *I learned* was *that*, especially in a manufacturing environment, if you *go* down there and tell a process operator to do something, he's going to look at you like, "What is this kid telling me what to do for?" But if you'll go down there with him and get in the hole with him and dig out some mud, that guy's going to respect you no matter what. You're willing to get down there and do it. I learned from *my boss that* it's not a big deal to go get covered in mud. You can *always* change later but that *process operator is* going to respect you a lot more for it. It was probably the best experience of my four years here. I realize *now* that college is a lot more about, not necessarily what you learn in class but what you do outside of class.

Jake's individual experiences that led to an interest in engineering were typical of many of the students interviewed. He was interested in and excelled in math and science; he enjoyed playing with Legos and K'Nex; he liked to take things apart and then attempt to put them back together with varying degrees of success. He also had a supportive family, including an uncle who was a practicing engineer, who stimulated his interests and encouraged him to think about the engineering field. Although each individual occurrence was representative of what led a large number of other interviewees to engineering, Jake's experience was atypical in that he cited all of these events as influencing his decision to pursue engineering. The emotions he described in the enjoyment phase were both positive valence and high activation.

As he began his program of study, these positive emotions were replaced with feelings of intimidation, nervousness, and eventually doubt. The first experience he described, that of sitting in the back of the MATLAB class, quiet and wondering about the usefulness and applicability of the class, represented not only a shift from positive to negative emotions but also from high activation to low. Pekrun and Linnenbrink-Garcia link negative, low activation emotions to decreased effort and "shallow information processing rather than any more intensive use of learning strategies" [39, p. 267]. As Jake continued his descriptions of his early classes, the valence of emotions described remained negative, but the activation shifted from low to high. As he recounted his difficulty with physics and calculus, he described increasing anxiety about his ability to remain not only an engineering major, but also a college student. Although low activation negative emotions most often lead to low motivation, the effects of high activation negative emotions are less consistent [27, 40, 41]. Pekrun and Linnenbrink-Garcia note: "These emotions often show negative overall correlations with effort, but in some cases, they may support behavioral engagement as they can serve to energize students" [39, p. 267].

Jake described breaking out of the cycle of frustration, discouragement, and doubt by employing a variety of coping strategies. He drew on family support, citing the encouraging words of his mother as being particularly impactful. Recognizing that he did not know how to study because good grades had always come easily to him, he learned how to access help from peers and professors. As he began attending office hours, Jake developed relationships with his professors. This in turn led to a professor stopping Jake in the hallway and encouraging him to apply for a co-op, despite his sophomore status and lack of preparation for the meet and greet that day. The co-op turned out to be a transformative experience for Jake; he described feeling like a different person upon completing the co-op.

Jake's descriptions of his early classes and experiences were typical when compared to first and second year students; however, he was an anomaly among fourth year students. Whereas many of Jake's recalled emotions still seemed raw at the time of the interview, the majority of older students' retrospective accounts described a softened version of the experiences. Sam, a civil engineering student, offered:

> Statics was my hardest class, but thinking back on it, it seems really easy now. Going through that experience allows you to think differently and be a better critical thinker. It's an enjoyable subject. Going through the class, it wasn't fun, but looking back on it, it was kind of fun.

Another student who shared Sam's perspective described the hard classes as "Type 2 fun. It's fun after the fact."

Although the coping strategies Jake employed helped him push past the feelings of stress and discouragement, it was the co-op he participated in that facilitated connected knowing. His initial doubt with his ability to contribute to a process and mechanical engineering environment as a structural engineer soon gave way to recognizing the role he could play. He described the skills he learned at the job site that he had not learned in the classroom, including professional communication, interpersonal skills, and collaboration. These 21st century skills are representative of connected knowing and are reported to be more valued by employers than separate knowing [42].

In Jake's narrative a critical event in his identity development was when he moved into professional practice through a co-op. This critical event marks a time when his paradigm shifted from one where he was a mediocre student without much confidence towards being an engineer with expertise and who others looked to for mentorship and leadership. As Jake began to develop a sense of his developing engineering identity, he began to seek out information and generally behave in ways consistent with their perception of that identity [43]. Jake became more attuned and receptive to knowledge that he perceived as being relevant to an engineering identity. When he returned to school after his internship and began to mentor other engineering students and encourage them to do internships, he demonstrated his perception of an alignment with an engineering identity. Additionally, higher activation emotions and more fluid thinking skills are associated with personally relevant experiences and material [44]. Thus, after Jake's experience in his internship, he began to perceive how course content is applicable in certain professional contexts, in other words, Jake began to see himself as being connected with the information being presented. This brings in another facet of connected knowing, as it also refers to students' capability to internalize and personalize knowledge.

4.2 Libby's narrative and analysis

> My senior year of high school, I volunteered at *a medical center*, and I got to see this robot. It was controlled by the surgeon, but the robot actually did the surgery itself. It was pretty cool. I'd always planned on going to pre-med and becoming a doctor. Then I visited *another college* and they were talking about *biomedical engineering* and I became interested in the prosthetics and stuff. I didn't realize there were medical sides to engineering *before.* They were talking about, studying abroad and going out of the country and helping those less fortunate, with creating prosthetics and stuff. It just appealed to me more than just being a regular doctor because you're actually *doing* hands on kind of stuff. After *the robot* and the biomedical stuff, I figured I want to do something with mechanical or the biomedical *engineering*.
>
> *So far school has been* pretty stressful. There is definitely a lot of work that you have to put in, too, especially for this major. You definitely can't slack off. It's more than what I'm used to. Then I'm also minoring in music, so that's a pretty heavy workload. I also have a part-time job at home. That's a pretty heavy workload, juggling *piano and classes.*
>
> I'm actually taking statics for the second time. The first time I made below a B in a class, so *it was* kind of an ego *blow*. I guess what frustrated me was that I went to my professor's office hours almost every day that it was offered. I got extra help where I thought I needed it, and I still didn't end up doing well in the class. I just don't understand what I could've done more, because I mean I did his homework problems, I did practice problems from the book to study, and it just didn't come out as I hoped. It definitely made me wonder if biomedical *engineering* was what I should be doing, where I should be going or heading towards, because I think statics is the first real engineering course that most people take. I felt that if I can't pass that, then how am I supposed to pass everything else?
>
> I'm afraid to ask the professor for help *during class* because I feel like they're going to say no and not help, like they can't tell me, so I don't ask. Actually, I do that in a lot of my classes, too. I've seen it happen to other people. I just don't want to embarrass myself, I guess. I don't know why that scares me, to ask questions *during class*, but it does. I don't want people to know that I wasn't paying attention at that one point; it's embarrassing. I don't want to be that student that people are like, "Wow, are you even in this class?" Because I know I have those moments. I just take a note of what I don't understand, and I'll go back over it myself.
>
> *I play the piano to* kind of escape from all the stress. Like if I'm tired of statics or something, I'll take a break and go practice piano. It's just something I really enjoy. It's not really like a chore. It's like I'm not even doing work, because I actually enjoy doing it.
>
> *I took statics the next semester* with a different professor, because I heard a lot of better things about him and how he teaches. The second time around learning things, *is* a little easier. Learning from a different professor, you take a different point of view on it. It's both challenging and simple at the same time. It's different, because I have to go in a different way of how to solve problems, but then I can always use what I already know and apply that to solving problems. Now, when I am stuck with something, like this past test, I did go up and ask, because I figured . . . I mean, the worst he could say was no, and I would just be wherever I started.
>
> Even though I didn't pass it the first time, it doesn't really change my mind about doing biomedical. Everything has its challenges. It's just one class so far, so I still want to keep trying. I'm not one of those people who just fail and give up and do something else.
>
> *Other classes have different challenges.* MATLAB is probably important but unfortunately, when I took that class I didn't know it would be, so I just learned stuff to learn it for the test. He kind of made it a boring class. It was like I wasn't motivated to really learn, and it didn't . . . It was hard to make it seem interesting, I guess,

and he never made it easy to just breeze through it, because for our projects, the majority of the program would be written for us, and so we would just have to figure out the ending, so . . . I feel that I didn't have to use my brain in order to really try to figure out how to use the program. I was spitting out whatever I saw on the paper.

Now I'm in circuits class and we're using MATLAB, and I don't remember a lot of it. I see that that would probably be important, especially if I go into the robotic side of surgery and stuff. I need to relearn how to do that, in order to pass that part. *So now I have a* little bit more work to do, a little bit more outside studying and effort. I definitely am going to have to remember how to use it.

My engineering design class is really interesting. It's really cool to see how *people* think and how creative they are, because a lot of them come up with ideas that I wouldn't have thought of on my own. Like our product that we chose right now is some kind of alarm clock that wakes you before you get into a deep sleep, so that it's not too hard for you to wake up when you need to wake up. We needed to come up with different concepts of design for that particular project. They're just throwing out ideas, and it's really . . . It's cool to see how other people think and how smart they are.

In circuits, for our labs, sometimes we're allowed to work with one another. I usually work with another girl that I met in that class. She has background knowledge in putting the circuits together, and so she's taught me how to do that. I feel that if I didn't meet her, I would have trouble with that part. She's helping me learn how to connect the wires and stuff like that.

I'm surprised by how many girls are in my classes. You'd think that engineering is like a more male kind of field, but there's actually a good amount of females in my classes. There's still a lot less than there are men, so it feels like a little bit of competition to me, like I have to be one of the best women because there aren't as many *here.* I guess it's more of a reason to stay. It makes it a challenge for me. It makes me more determined to finish with this degree, because if guys can do it, so can girls. I don't think it was a reason to get into *engineering*; it's more of a reason to continue with it.

Unlike Jake and many other participants, Libby's story did not include a childhood filled with Legos and dismantled remote controls. Her interest in engineering was piqued during a volunteer experience in her senior year of high school during which she learned about robotic surgery and prosthetic construction. Her interest in these activities, coupled with a desire to help people, led her to choose biomedical engineering as a pre-med major instead of the more typical biological science major.

Freshman year was a stressful time for Libby. She cited a heavy workload, a minor in music, and a part-time job as contributors to the stress. Failing a statics class only served to amplify the discouragement and frustration she felt. Libby sought help from the professor during office hours, which we learn later in the narrative was outside of Libby's comfort zone, but was still unable to pass the class. This first experience with failure coupled with an inability to identify anything she could have done differently to affect a different result, caused Libby to question her belonging in the biomedical engineering program. She later identified that she has forced herself to become more comfortable asking questions during class.

MATLAB was another source of stress for Libby, this time due to boredom and a perceived lack of challenge rather than being unable to pass the class. Libby described feeling disconnected from the class, which focused on rehearsal and recall, leading to a sense of boredom and a lack of motivation to learn the material in depth. "I feel that I didn't have to use my brain in order to really try to figure out how to use the program," she said. "I was spitting out whatever I saw on the paper." These negative valence, low activation emotions, also experienced by Jake, led to difficulty in some of Libby's future endeavors. Although Libby passed the class, the shallow processing of the MATLAB material became problematic as she began her circuits class. The lack of connected knowledge hampered her ability to apply the MATLAB material to problems arising in circuits, thus prompting her to return to the MATLAB material on her own to relearn it.

Libby eventually relied on coping skills and persistence to help push through the frustration stage. Playing piano was a source of tension relief during the stress of statics. She overcame her embarrassment about asking questions in class and began to call on her professors for help. Drawing inspiration from group projects and the collective creativity she experienced working with her peers, Libby began to turn to peers for academic help as well. When students come together in this way, it has been suggested that two different kinds of personal connections are being formed: disciplinary and social [45] and Libby's narrative supports this theory, however these connections can be complex, as is seen in this narrative when Libby discusses the small number of women in engineering being a provocation. She was simultaneously moved to compete with and represent women in engineering.

Her citing it as a reason she stays in the engineering program denotes the importance of this factor for Libby.

A critical event in Libby's trajectory and identity development is when she did not pass statics the first time she took it. She considered dropping out of engineering, but then decided to stick with it. When she took the class again she began asking questions in class, something that she was uncomfortable doing because of her concerns of how other students would perceive her. She explained, "I'm not one of those people who just fail and give up and do something else," and this shows that she is changing her personal narrative to one of a person who does not give up when classes get hard. This is likely a turning point in her engineering identity development as she has encountered difficulties and decided to stick with engineering.

Fleming et al. [46] found that primary reasons students leave engineering are "(1) lack of faculty guidance/advisement; (2) lack of community engagement; (3) scholarship/financial dilemmas; and (4) course difficulty (p.3)". The 2008 Pathways study [47] stated "reasons for staying include sponsorship of student strengths and skills, satisfaction of completing a rigorous course of study, the desire to contribute to the public good, and a vision of the potential for a comfortable lifestyle following graduation." Students who are able to thrive despite the rigor of the engineering program are often called persisters [48]. They display a trait called doggedness, which consists of "perseverance, tenacity, and the ability to stubbornly adhere to a course of action (p. 3)". Dogged students don't need a high level of satisfaction to persist and can develop strategies for overcoming frustrations. This doggedness is seen in both Jake and Libby's narratives.

5. Implications

One implication that emerged from this narrative analysis was the importance of social networks within the narratives of students, especially when they were very stressed and anxious. These social networks included relationships with family members (e.g., Jake's mother), peers (e.g., Libby's partner in her circuits lab), professors, (e.g., the professor who encouraged Jake to attend the career fair), and friends. As a faculty member, our interactions with students can have significant impacts on their trajectory in school and on their emotions. Previous studies have found that faculty interest and involvement affects student engagement, and satisfaction with their college and home department [49–52]. Connected knowing encompasses the multiple ways that students personally connect to what they are learning. When students feel greater respect and empathy towards the deliverer of information, they have more impetus to connect with that information. It is incumbent upon faculty, then, to show commitment to student growth and education and to make themselves apparently available to student questions and concerns, or simply "just to talk."

Developing a relationship with students does not mean simplifying work, however. In fact, one third of students interviewed referred to a feeling of being challenged in their studies leading to greater engagement and the sense that they were "learning." Arum and Roksa suggest that the greatest learning occurs when students have "faculty members who are . . . approachable and [have] high standards and expectations" [53, p. 93]. Using the lens of connected knowing, this makes sense. More difficult work can produce higher activation emotions, such as frustration or anger, which are associated with metacognition and higher-order thinking strategies. In a scenario where the student experiencing such high activation emotions also feels a strong bond with the professor (and the emotions that accompany that bond), it is easy to see how the student may persist through the difficulty to reach greater understanding. Both the high activation emotion and the connection with the professor make course material more personal, leading to greater connected knowing.

Another implication of this research is the importance of making course material relevant for students in fostering connected knowing. Nearly every student in the study described struggling with at least one of three courses (MATLAB, statics, or AutoCAD) and many of them reported that the relevance of these classes was unclear. Four students described coming to understand why those courses were important after more time in the engineering program, but fourteen students discussed feeling more engaged with courses when the applicability of course content was clear. If this is the case, it is important for professors teaching entry-level courses to explain how and why course material may be relevant to students. One student discussed interactions with a calculus teacher who "made sure every time we had examples or anything, he always loved talking about rockets. So he would always bring up the physics of it and we were assigned specific problems that involved rockets all the time. It really seemed to be useful." Another student described how it helped her to have "the story" (context) surrounding course material for her statics class, rather than memorizing particular figures. Additionally, nearly half of the student interviewed described co-ops and internships as potential sites to apply course content and develop hands on knowledge.

Highlighting the relevance and real-world application of course content is not simply a courtesy to students. Connected knowing refer to students' capability to internalize and personalize knowledge. As students begin to develop a sense of their developing engineering identity, they will seek out information and generally behave in ways consistent with their perception of that identity [43]. This means that they will be more attuned and receptive to knowledge that they perceive as being relevant to the identities they are beginning to inhabit. Additionally, higher activation emotions and more fluid thinking skills are associated with personally relevant experiences and material [44]. Thus, using real-world examples does not simply show students how they might use course content in applicable contexts, but it provides a way for students to connect themselves with the information being presented.

6. Conclusions

By combining thematic analysis of narratives and narrative analysis from interviews with a diverse set of engineering students, we are able to report on emotions commonly encountered during the undergraduate engineering education experience. Our findings suggest a trajectory of emotions including enjoyment of pre-engineering activities, nervousness about core classes, frustration and discouragement with core classes, and, towards the end, an overall happiness or contentment with their education experience.

Future work is needed to understand more deeply the role of emotions in engineering student learning. In this paper we presented an emergent emotional trajectory and two constructed narratives. In future work we plan to develop a deeper understanding of the types of emotions present in students trajectories, the valence of those emotions, and the activation of those emotions. We also plan to develop an understanding of any differences in the emotions experienced between majority students and underrepresented groups. Finally, we plan to develop a better understanding of learning as encompassing both connected and separate learning. While we are interested in exploring connected knowing and its implications in engineering, we are not advocating for removing separate learning from the curriculum. We agree with Clinchy, who explained, "I do not object to the cultivation of separate knowing in the academy. I believe it is important to teach the skills of separate knowing. But I do object to an educational system that places nearly exclusive emphasis on separate knowing and fails to acknowledge with respect, let alone to nourish, the skills of connected knowing" [5, p. 65].

In this project, we have explored the roles of emotions in engineering student learning, and have set the stage for beginning to understand connected knowing in engineering education. In our thematic analysis of the transcripts, we found negative, high activation emotions to exist in most of the student's narratives, thus being common in their engineering program. What is of interest is how the presence of these high activation, negative emotions have on the development of engineering students. Students who were further along in their program tended to look back on prior experiences as being critical for their development as engineering students. Moreover, they also expressed that they felt like more validated members of the community. These students have persisted through this negative experience, and now perceive themselves as belonging in the community.

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