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An Investigation of Self-Efficacy and Topic Emotions in Entry-Level Engineering Design Learning Activities*

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Little is known about the impact self-efficacy and topic emotions have on novice engineering students when first exposed to an engineering design course. Freshman students may have difficulties regulating their emotions when exposed to new or complex topics such as engineering design. Consequently, they may become frustrated or discouraged as the semester progresses that can lead to feelings of hopelessness and anxiety. In contrast, novice students may experience feelings of hope and interest that may foster positive learning outcomes in engineering design. The authors explored freshmen engineering students' (n = 58) levels of self-efficacy and topic emotions while participating on a freshmen-level engineering and graphics design course. Our findings suggests that while positive and negative topic emotions are inversely related, both seem to be associated with self-efficacy. Further, topic emotions appear to mediate self-efficacy as topic emotions such as curiosity, happiness, and interest were reported by engineering students during engineering design activities. Self-efficacy increased over the course of the semester for these freshman engineering design students.

Keywords: engineering design; self-efficacy; topic emotions

1. Introduction

Over the past decades, national attention has focused on promoting science, engineering, technology, and math (STEM) degrees [1–4]. Particularly, engineering professions are in high demand [1–4]. As such, engineering educators are tasked to produce not only technically competent professionals but to encourage students' development of 21st century skills such as teamwork, communication, problem solving, and critical thinking. While educational initiatives have focused on helping engineering students develop these 21st century skills, it is still unclear how instructional approaches used by engineering educators can influence students who may be new to their field [5].

Novice engineering students are at higher risk of leaving engineering compared to their senior counterparts [5]. For example, students who drop-out of engineering in their freshmen or sophomore years have stated that reasons for leaving engineering include seeking an "easier" field [6]. Others studies suggests that these engineering students become discouraged to continue in the field due to the high demands of the discipline [7-10], discordances to their professional and personal interests [11–14], and feeling more personal satisfaction when seeking a more "fulfilling" field [15]. Yet, these speculations do not identify the underlying factors for this withdrawal [5].

The authors propose that one factor that may contribute to novice engineering students' lack of persistence in their courses could be their emotional response to challenging engineering learning activities (e.g., design). Entry-level engineering design courses are designed to provide students with authentic experiences such as design failure [16] to help students learn to overcome such phenomenon early in their education. When engineering students are first exposed to these types of ill-structured projects, students may experience cognitive blocks [17] that can intertwine with their emotions [18, 19] and influence their performance [19]. Moreover, new or ill-structured engineering design problems can introduce emotions such as anxiety and fear to novice students [20, 21]. The challenge lies on whether these students can regulate their emotions in a timely manner or not, as literature suggests that when certain deactivating emotions persist (e.g., fear, frustration, and anxiety) learning is impeded and motivation is hindered [22–24].

A second likely factor is students' self-efficacy. Self-efficacy is the learner's beliefs that they can successfully plan and achieve a goal [25]. Novice engineering students often lack the needed skills and understanding of engineering processes to recover from learning activities that are constructed to promote intentional setbacks and possible failure related to engineering design [26–29]. This, in turn

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can be due to an individual's low levels of self-efficacy that are associated with their level of understanding of a problem [30]. Thus, students with low self-efficacy are more likely to quit when faced with difficult challenges [25, 31].

The authors expect that this challenge may arise when freshman engineering students first encounter engineering design experiences. The potential associations between self-efficacy and topic emotions during engineering design experiences for novice students has been understudied [32, 33]. This work aims to investigate these potential associations.

2. Literature review

2.1 Theoretical framework

The structure and design of an engineering curriculum has been suggested to exacerbate the unemotional classroom climates that continue persisting in the field [34–36]. In contrast to the rational approaches to engineering education, the authors argue that emotions are interrelated with cognitive processes that are involved during learning activities [32, 33, 37, 38]. The relationship between emotions and cognitive processes is well supported by the literature in social psychology [39]; [40], cognitive psychology [41, 42], and educational psychology [22, 43–45] but has not been tied as much in engineering education [14, 32, 33]. In the following sections, the authors provide a brief description and summary of the research conducted on the theoretical frameworks of academic emotions (and more specifically topic emotions) and self-efficacy in learning contexts as a lens, particularly for undergraduate engineering design courses.

2.1.1 Academic emotions

Psychologists have argued that cognition and emotions are inextricably linked [39, 46]. In line with Rosenberg [47] and Pekrun's definitions [24], the authors view emotions as quick, automatic affective responses to a specific referent that often occur unconsciously [47] and that consists of "multiple component, coordinated processes of psychological subsystems" [24, p. 316]. Based on these two definitions, the authors view that emotions in learning have a mediating role in motivation, cognitive processing, cognitive engagement, and achievement outcomes.

Over the past decade, psychologists and educational psychologists have begun to investigate *academic emotions*. Academic emotions are those emotions experienced by individuals during learning contexts such as receiving instruction from a teacher or studying for an exam [48]. Pekrun and colleagues [24, 25] postulate that academic emotions consist of two dimensions: valence (positive/negative) and activation (activating/deactivating). Positive activating emotions, such as enjoyment and hope, may increase critical thinking, elaboration, and metacognition, while positive deactivating emotions such as relief and pride are likely to result in low levels of cognitive processing. Similarly, negative activating emotions including anger and anxiety may spark increased engagement and elaboration; though negative deactivating emotions (e.g., boredom, hopelessness) may have the opposite effect, dampening motivation and promoting superficial processing [18, 24, 49].

It is possible that students who have engaged in challenging engineering tasks that involve multiple trial-and-error problem-solving situations may experience enjoyment if they find pleasure in developing solutions to difficult tasks. In contrast, students who have typically been successful in generating effective engineering designs may experience discouragement and perhaps frustration when the learning activity is one that has been developed purposefully to have students experience setbacks and possibly failure. There is still a lot that needs to be explored about the types of emotions present in undergraduate engineering design courses and its correlations to self-efficacy and learning outcomes [14, 32, 50].

It also may be the case that students can experience other emotions such as curiosity, confusion, interest, anxiety, or fear during an engineering design activity. Indeed, the initial investigation into students' academic emotions during classroom learning activities in other disciplines such as psychology have suggested that students could experience the full scope of emotions at one time or another [48]. Frenzel, Pekrun, and Goetz [51] demonstrated that undergraduate students can experience a range of emotions while learning science, including anger, frustration, curiosity, interest, disgust, and anxiety.

2.1.1.1 Topic emotions

Students' academic emotions can be classified into subsets (i.e., topic emotions) [32, 33, 53]. Topic emotions are sparked when a student is learning about a particular topic in the classroom [22, 52]. It may be that when exposed to a course topic, a learner experiences positive emotions, such as enjoyment, hope, and pride. However, that same learner may experience feelings of anxiety, worry, and fear when a new concept within the topic is presented.

It is important to note that topic emotions are viewed as two dimensions, positive/negative and activating/deactivating [45, 48]. Additionally, the intensity of emotions could differ from these two dimensions in that it deals with the level of emotion felt by the learner [43]. For example, previous research [43] found that students experienced anger (negative/activating) at high levels prior to an instructional intervention. After the instructional intervention, these same students reported lower levels of anger (negative/activating).

Also, literature suggests that certain topics can elicit high levels of negative emotions that can be tempered by instruction [54] and across the span of a semester [22, 33, 55]. Studies have been conducted on topic emotions at the K-12 level [22] and at the undergraduate level [23, 56] and both have shown that students emotionally respond to course topics. For example, Linnenbrink and Pintrich [23] showed that negative emotions such as anxiety decreased as students learned and became more comfortable with topics such as projectile motions. Schorr and Goldin [56] showed that when mathematical topics on unknowns (e.g., negative numbers) are first taught to students, they experience domain-specific topic emotions such as pride and boredom, according to their problem-solving approaches.

Depending on the nature and duration of a course subject, topic emotions can be *state-like*, which consists of those ''immediate and rapidly changing emotions'' [55, p. 395] or *trait-like*, that comprises a ''longer-term and relatively stable characteristic'' felt during the semester or year where a particular topic is covered [55, p. 395]. In addition, topic emotions can be domain-specific [18], vary by instructor [54, 57] and discipline [18, 52]. We have not found any research that has investigated the role of students' intrinsic differences (e.g., their self-efficacy) and topic emotions. This idea guided our study which presents the findings of topic emotions as they relate to self-efficacy from a group of 58 engineering entry-level students introduced to the topic of *engineering design* throughout an academic semester. The findings of this study represent a secondary set of ideas and data collected as part of a larger study [32].

2.1.2 Self-efficacy

Self-efficacy consists of an individual's belief in their ability to succeed in a specific situation, goal, or task, even if the circumstance may be difficult to pursue [25, 58]. Bandura [25] suggests that self-efficacy is task and context-specific and as such, this construct has been explored in courses such as math [30, 59] and science [60]. Individuals that self-report initial high levels of self-efficacy perform better in subjects such as math compared to their low self-efficacy counterparts [61] and is believed to mediate gender differences in student performance [30] as well as academic emotions in specified classroom contexts [62].

The literature suggests that there are four sources of self-efficacy in the classroom [25, 63]: (a) vicarious experiences; (b) social persuasion; (c) emotional and physical state; and (d) mastery experiences. Vicarious experiences involves those skills that are modeled by the instructor, through simulations and by peers through group projects. Social persuasion involves feedback from instructors or peers about an individual's ability to accomplish tasks and their effects tend to be short-term [25]. Physical and emotional states may have separate effects: positive states may enhance efficacy, while negative states may constrain efficacy for learning. Mastery experiences enhance self-efficacy for learning when the task is perceived as challenging and with a likelihood of success. However, when failure occurs, self-efficacy via mastery experiences could be diminished. In accordance with previous research, the authors treat the engineering design sub-topics studied in this work as mastery experiences [64].

In engineering education, little is known about the influence of self-efficacy and academic achievement in a course or course topic. For example, Jones, Paretti, Hien, and Knott, [65] investigated first-year engineering students' levels of self-efficacy over the course of the academic year. The findings showed that self-efficacy was predictive of GPA but students' self-efficacy decreased from the beginning of the academic year to the end of the academic year. On the other hand, if self-efficacy was studied over time in an engineering course, a sequential spike in self-efficacy was found over the span of a semester [65]. Thus, the purpose of this study was to explore students' self-reported topic emotions and self-efficacy during different stages of engineering design course for entry-level engineering students in a single discipline (i.e., Mechanical Engineering).

3. Method

3.1 Research design and questions

Our specific research questions for this study were: (1) What topic emotions are present in a freshman engineering design course at the beginning, middle, and end of the semester?; (2) What are the levels of engineering students' self-efficacy at the beginning, middle, and end of a freshman engineering design course?; and (3) How do engineering students' topic emotions and self-efficacy associate throughout the semester of an engineering design course?

The authors expected that engineering students would experience a range of topic emotions, such as anxiety, interest, curiosity, frustration, fear, and hope. Our prediction was expected to be consistent with Pekrun and colleagues' [48] study of undergraduate students' academic emotions where they found a corresponding increase in self-efficacy over the course of the semester. Further, the authors expected that positive valence emotions would correlate positively with high levels of self-efficacy. In contrast, the authors expected that negative valence emotions would have an inverse correlation with self-efficacy.

3.2 Participants

Freshmen engineering students were purposefully selected for this study because literature suggests that this is a pivotal year where students decide to continue on to other engineering courses or drop out [6, 66]. Fifty-eight participants out of a class of eighty-eight students enrolled in the class agreed to participate in our study. The course is undergraduate engineering design and graphics course at a western U.S. university. The majority of participants were male (90%), White (98.28%) and declared as Mechanical Engineering majors.

3.3 Materials

The authors used the Emotions about Engineering Design [22, 32, 33] instrument to assess participants' in-the-moment topic emotions on the beginning, middle, and end of the semester. Thirteen emotions on a five-point Likert scale were included on the survey instrument. Emotions included, hope, anger, anxiety, boredom and enjoyment. This survey was used in previous studies and has consistently shown mid-to-high reliability coefficients (0.67 to 0.91 for positive topic emotions and 0.80 to 0.93 for negative topic emotions) [22, 33]. The survey instructions were, "*The authors are interested in the types of emotions you experience when thinking about engineering design. For each emotion, please indicate the strength of that emotion by selecting the number that best describes the intensity of your emotional response*."

The Self-Efficacy for Engineering Student (SEES) scale measured student self-efficacy for learning to solve problems in an engineering course and was created based upon Bandura's [67] guide for creating self-efficacy surveys. The SEES instrument consisted of 10 items, each related to a different stage of the UTeachEngineering Design cycle [68]. Participants were asked to "Rate your degree of confidence in your ability to do these individual learning activities by selecting a number from 0 (*Cannot do at all*) to 100 (*Highly Certain Can Do*)." All items were phrased to explore general and task-specific engineering skills. Sample items included, "Identify the key features needed to tackle the design problem," and "Overcome constraints in carrying out the final design." Previous Cronbach alphas ranged between 0.75 and 0.93 [24, 69].

The two instruments were developed and validated in prior studies [32, 33]. To briefly summarize, face validity occurred for the content of the instruments via consultation of the questions with a group of educational psychologists, psychometricians, and engineers as discussed elsewhere [32, 33]. Further validation of the two instruments were established by exploratory factor analysis and more specifically, using principal component analysis. These values are partly included in this manuscript and further elaborated in other studies [32, 33]. Accompanying the two surveys was a 28-item demographic survey administered to each participant in order to obtain information about that students' academic status, prior engineering design experience, gender, and so forth.

3.4 Procedure

All items of this work was approved for human subject research by the Institutional Review Board at the home institution of the authors. Before the study commenced, participants completed a demographic survey online that was distributed with the help of the course instructor. Then, students participated in several engineering-based activities over the course of the semester (3, 6, 9, 12, and 15 weeks). The design activities centered around the simplified steps of the UTeachEngineering framework [70] and relied on instructional activities aimed at promoting decision-making, teamwork, and idea generation in student teams [71, 72]. Both the topic emotions survey and the self-efficacy survey were administered during the classroom activities using online survey links that students can access to easily. The authors examined the data from activities during the third week (beginning), ninth week (middle), and fifteenth week (end). The authors collected achievement scores related to each activity and the tally of that score at the end of the semester.

4. Results

Individual emotions fell into two groups. Individual emotion means and standard deviations can be found in Table 1 for the third (beginning), ninth (middle), and fifteenth (end) week of the semester. Students tended to report moderate to high levels of positive emotions and low level of negative emotions across the three administrations. Of all 13 emotions, curiosity and interest had the highest rankings at the beginning of the semester, while hopefulness and happiness were the highest ranked at the end of the semester. Anger consistently was the lowest ranked.

The authors computed Spearman rho correlations for each activity because each emotion measure consisted of one Likert item. Correlations tended to cluster in two groups: positive and negative valences. Positive emotions including hope, curiosity, happiness, interest and joy showed mod-

Table 1. Means and standard deviations of individual emotions across the beginning, middle and end of the semester; topic emotions are listed in the order presented in the survey

	Beginning	Middle	End
Angry	1.42 (0.71)	1.52 (0.73)	1.27 (0.46)
Hopeful	3.58 (0.79)	3.68 (1.03)	3.55 (1.06)
Anxious	2.71 (0.97)	2.23 (1.05)	2.27 (0.94)
Boredom	1.90 (0.81)	1.80 (0.90)	1.55 (0.91)
Curious	3.98 (0.86)	3.20 (1.07)	3.05 (1.09)
Happy	3.63 (0.84)	3.45 (0.98)	3.41 (0.96)
Fearful	2.04 (0.99)	1.77 (0.83)	1.59 (0.67)
Confused	2.31 (0.97)	1.93 (1.04)	1.73 (0.55)
Interested	3.87 (0.73)	3.48 (0.90)	3.14 (1.17)
Surprised	2.08 (0.99)	1.82 (0.90)	1.82 (0.80)
Frustrated	2.10 (0.93)	1.91 (0.98)	1.95 (0.79)
Hopeless	1.56 (0.68)	1.55 (0.82)	1.64 (1.00)
Enjoyment	3.48 (0.90)	3.57 (1.00)	3.32 (1.00)

erate to strong positive correlations with correlations ranging from 0.22 to 0.84 between each engineering design activity. Similarly, negative emotions, including anger, anxiousness, boredom, fear, and frustration, had weak to strong positive correlations (*r*'s = –0.01 to 0.85). Surprise and confusion showed consistent weak to moderate or weak to strong positive correlations with negative valence emotions (e.g., surprise, *r*'s = –0.08 to 0.55; confusion, *r*'s = –0.01 to 0.73).

Next, the authors conducted a principle component analysis to explore if positive and negative emotions would load into two representative factors. The authors identified components using scree plot and eigenvalues greater than one. The total variance explained ranged from 52.57% (beginning of semester) to 65.72% (middle of semester). Consistently, a two-component model around valence (positive or negative emotions) was found to be the best fit as shown in Table 2. Positive and negative topic emotions were the best fit of the data through confirmatory factor analysis for the first ($c^2 = 68.08$, $p = 0.01$, CFA = 0.89, RMSEA = 0.11, SRMR = 0.14), third ($c^2 = 64.66$, $p = 0.07$, CFI = 0.96, RMSEA = 0.08, SRMR = 0.11), and fifth engineering design activity ($\chi^2 = 94.97$, $p < 0.0001$, CFI = 0.72, RMSEA = 0.23, SRMR = 0.17). Surprise and confusion loaded on the negative component. Boredom cross-loaded on both factors and was excluded from further analysis.

The authors conducted correlations between the positive and negative emotion scales and the self-efficacy scale. The authors found the self-efficacy scale correlated moderately with academic emotions. Meanwhile, positive correlations with positive valence emotions were found and negative correlations with negative valence emotions were found. As seen in Table 3, significant correlations

Table 2. Principal component analysis of academic emotions for all engineering design activities; bolded values represents an Eigen value above 0.40 indicating a predominance of a particular topic emotion and dimension

Time	Beginning		Middle		End	
Valence	**Negative**	**Positive**	**Negative**	**Positive**	**Negative**	**Positive**
Topic Emotion						
Angry	**0.47**	0.23	**0.72**	0.18	0.14	**0.59**
Hope	0.31	**0.73**	0.37	**0.77**	0.15	**0.80**
Anxious	**0.67**	0.14	**0.69**	0.10	**0.46**	0.21
Boredom	0.10	0.10	0.35	0.36	0.34	**0.40**
Curious	0.13	**0.78**	0.16	**0.72**	0.01	**0.85**
Happy	0.22	**0.78**	0.24	**0.82**	0.05	**0.93**
Fear	**0.78**	0.14	**0.86**	0.09	**0.62**	0.14
Confusion	**0.79**	0.27	**0.90**	0.02	**0.57**	0.22
Interested	0.27	**0.57**	0.01	**0.90**	0.19	**0.88**
Surprised	**0.73**	0.41	0.71	0.18	**0.70**	0.40
Frustrated	**0.75**	0.08	**0.83**	0.20	**0.68**	0.26
Hopeless	**0.68**	0.20	**0.90**	0.16	**0.75**	0.10
Enjoyment	0.03	**0.83**	0.05	**0.89**	0.14	**0.88**

Table 3. Pearson correlations between self-efficacy (SE), positive (Pos) and negative (Neg) topic emotions across the three engineering design activities (subscript '1' for beginning; subscript '3' for middle; and subscript '5' for end); * p < 0.05; ** p < 0.01

	SE 1	Neg 1	Pos 1	SE 3	Neg 3	Pos 3	SE 5	Neg 5	Pos 5
SE 1									
Neg 1	–0.39**								
Pos 1	0.33*	0.02							
SE 3	0.67**	–0.61**	0.24						
Neg 3	–0.36*	0.67**	–0.11	–0.71**					
Pos 3	0.36*	0.01	0.54**	0.44**	–0.22				
SE 5	0.42	–0.19	0.41	0.53*	–0.02	0.43			
Neg 5	–0.37	0.55*	–0.12	–0.59**	0.71**	–0.18	–0.23		
Pos 5	–0.09	0.12	0.67*	0.22	–0.04	0.71**	0.46*	–0.03	

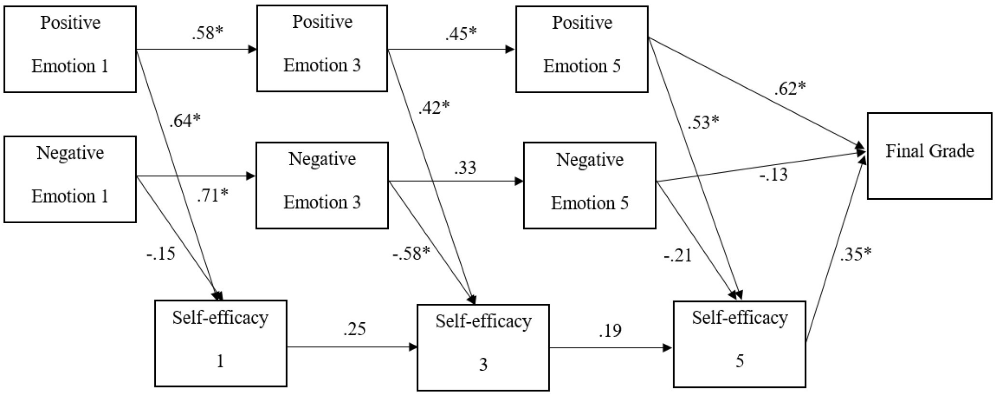

Fig. 1. Lagged path analysis showing changes in self-efficacy and topic emotions across the semester; * $p < 0.05$; beginning- denoted as '1'; middle- denoted as '3'; and end- denoted as '5'

between self-efficacy and the emotion subscales were within the same engineering design activity and not between the engineering design activities.

To examine how topic emotions and self-efficacy appeared throughout the three engineering design activities across a semester of this course, the authors conducted a repeated measure MANOVA. The interaction between topic emotions and time were not significant ($\lambda = 0.89$, $F_{(2, 19)} = 1.21$, $p = 0.32$). A significant main effect was found for topic emotions. Positive topic emotions was found to have higher self-reported means (M = 3.56) compared to negative topic emotions (M = 1.80; $\lambda = 0.70$, $F_{(2, 19)} = 4.06$, $p = 0.03$). The second analysis found that students' topic emotions as a whole dropped significantly ($\lambda = 0.21$, $F_{(1, 20)} = 75.15$, $p < 0.001$) between the beginning (M = 2.84), middle (M = 2.65), and end of the semester (M = 2.55).

The authors identified significant gains in the self-efficacy scale across the three engineering design activities as measured by a repeated measures ANOVA ($F_{(2, 40)} = 15.75$, $p < 0.001$, partial $\chi^2 = 0.44$). Significant differences in reported self-efficacy scores occurred between beginning (M = 804.18, S = 85.18) and middle (M = 885.24, S = 89.76) and between the beginning and end (M = 910, S = 80.87) of the semester. No significant differences in self-efficacy scores were found between the engineering design activities at the middle and end of the semester.

To explore the relationships between topic emotions, self-efficacy and academic achievement, the authors created a statistical model (Fig. 1) that could predict how each variable changed over time and influenced the subsequent engineering design activities across the semester (beginning- denoted as '1'; middle- denoted as '3'; and end- denoted as '5'). Topic emotions moderated self-efficacy in each engineering design activity as previously suggested by Campbell [62].

As shown in Fig. 1, positive topic emotions consistently had a positive influence on self-efficacy. Negative topic emotions had a suppressive effect on self-efficacy in the middle of the semester. Previous levels of positive topic emotions in the engineering design activities but neither negative topic emotions nor self-efficacy influenced the next engineering design activity measurement. Positive topic emotion at the end of the semester influenced both self-efficacy and the final grade, while the self-efficacy also contributed to final grade.

5. Discussion

The aim for this study was to explore how student's self-efficacy and topic emotions varied across the different activities around the topic of engineering design. Our first question was, "*What topic emotions are present in a freshman engineering design course at the beginning, middle, and end of the semester?*" Based upon the findings from Table 2, it was found that students reported experiencing moderate to high levels of positive topic emotions including hope, curiosity, happiness, interest, and enjoyment. In contrast, students reported experiencing negative topic emotions at a low level of intensity. The negative topic emotions factor remained constant and low across the three engineering design activities. On the other hand, positive topic emotions factor showed a small but significant decrease from the beginning of the semester to the end of the semester. Boekarts and Pekrun [49] suggested that positive emotions such as enjoyment can foster student engagement and attention on a task and may promote flexible learning strategies with problem solving activities. The students in the current study reported experiencing positive topic emotions throughout the semester of this engineering course.

Our second research question was, "*What are the levels of engineering students' self-efficacy at the* *beginning, middle, and end of a freshman engineering design course?*" Students' self-efficacy at the beginning of the semester was high and continued to increase in strength throughout the semester. Our work refutes Jones and colleagues [65] who found engineering students' self-efficacy declined. On the other hand, this study is consistent with research from Luzzo and colleagues [73] who found high self-efficacy in math and science were more likely to select math and science related majors. The authors agree that self-efficacy among university students is malleable; however, further research is needed to address this discrepancy.

Woolfolk-Hoy and others [64] have argued that mastery experiences are the strongest source of self-efficacy. The engineering course in this study focused on project-based service learning providing challenging tasks at which students succeeded. The difference in our results from Jones [65] may be that Jones' students were not challenged or were not successful in their performance of the task as these two variables were not included in their study. Students' perceptions of the degree of challenge were not measured in both Jones and colleagues [65] or in our present study.

Our third research question asked, *"How do engineering students' topic emotions and self-efficacy associate throughout the semester of an engineering design course?"* Correlations were as the authors predicted, with negative topic emotions inversely related to self-efficacy and positive topic emotions correlated positively with self-efficacy. Our findings align with Boekaerts and Pekrun [49] in that positive emotions (e.g., hope, enjoyment) are positively correlated with self-efficacy. Our finding concurs with Pekrun's control-value theory [24] who argue that both positive and negative achievement emotions can have a positive impact on student learning.

Collectively, our findings suggests that self-efficacy and topic emotions can vary across different engineering design activity contexts based on the skills and processes used during each workshop. For example, if a student has relevant prior knowledge and skills needed for one engineering design activity they may experience moderate to high levels of self-efficacy and positive topic emotions such as hope and curiosity. However, this same student may lack relevant prior knowledge and skills needed for a second engineering design activity and, consequently, they may experience low to moderate levels of self-efficacy and negative topic emotions such as fear and hopelessness. In this way, we view self-efficacy and topic emotions as being contextually situated based upon the nature of the engineering design activity.

6. Limitations

The authors recognize that the current study has limitations due to its exploratory nature. First, while the authors did measure academic emotions and self-efficacy over the duration of the semester, the authors did not collect academic outcomes for each design activity (e.g., project products, performance data). This limits our explanations of the findings as the authors are unable to study possible relationships between emotions, self-efficacy, and academic achievement by engineering design activity.

A second limitation to this study is the lack of confirmation of topic emotions being specifically associated with the tasks of the course; rather, it focused on the course in general. In our analysis, we focused on topic emotions at a general level while student engaged in these three engineering design activities. A more fine-grained level of examination of academic emotions could focus on task-related emotions [24] and allow us for a better understanding of these correlations in the future.

A third limitation is that the scope of the study only focused on one topic (engineering design) within one discipline (e.g., Mechanical Engineering). It is possible that other topics (e.g., calculus) may elicit different types of topic emotions as literature in math education suggests [55]. Future work will explore other courses and topics in engineering amongst a diverse set of disciplines.

7. Implications for practice

The structure and design of engineering curriculum has sometimes been described as having unemotional or stoic approaches [34–36]. In contrast to the stoic view of engineering education, the authors argue that emotions are interrelated with cognitive processes that are involved during different learning activities across the span of the course. The authors did not find any evidence of negative topic emotions in this course, which suggested students overall positive emotions related to the engineering design activities. Positive emotions has been shown to influence intrinsic motivation in students [23, 74].

Our results open the door to studies that could explore in more detail how topic emotions and self-efficacy are fostered through engineering instructional activities. Also, our data seems to suggest that with a continual and longitudinal presence of engineering design experiences, that positive topic emotions could remain among students whereas negative topic emotions could subside over time. This suggests the important role that trait-like course topics such as engineering design can have in helping students develop and sustain self-efficacies that will nurture a positive experience in the engineering classroom.

8. Conclusions

Our study contributes to the literature on our understanding of the role that topic emotions and self-efficacy plays in engineering design activities across a semester. While positive and negative topic emotions are inversely related, both seem to be associated with self-efficacy. Further, topic emotions appear to mediate self-efficacy as topic emotions such as curious, happy, and interested were reported by engineering students during engineering design activities. Self-efficacy increased over the course of the semester for these freshman engineering design students. While positive and negative topic emotions are inversely related, both seem to be associated with self-efficacy.

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