A cross-sectional study of engineering students' creative self-concepts: An exploration of creative self-efficacy, personal identity, and expectations

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Abstract

The purpose of this paper is to expand the research base on creativity by assessing engineering students' creative self-concepts. A cross-sectional study of first-year and senior engineering students was conducted to investigate three constructs that measure creative self-concept: creative self-efficacy, creative personal identity, and creative expectations. Gender differences in how creative self-concepts differ from first-year to senior year were also explored. The results show that female students have lower average scores on a creative self-efficacy scale at both the first and senior years. First-year female students have higher average creative identity scores than male students. However, senior male students have a stronger creative identity than senior female students. Senior males and females feel that instructors have lower expectations regarding creative behaviors as compared to first-year students. The lower expectation of senior students suggest that engineering instructors should consider ways to engage upper level students in creative behaviors. Future research includes a longitudinal study to examine how creative self-concept changes in progression through the engineering curriculum.

Introduction

The concept of creativity has been an important research topic since the 1950's and 1960's.[1] Educators and scholars with diverse domains of expertise have studied creativity, the skills associated with creativity, and techniques to increase creativity in their respective fields.[2-6] However, even in the field of psychology, where the most research pertaining to the topic has been produced, researchers suggest that the study of creativity is actually often neglected.[6]

Part of the difficulty in studying creativity is defining and operationalizing the concept, which may take on different meaning in different contexts. As a result, it is vitally important to examine creativity within a specific domain.[7] In engineering education, definitions of creativity often revolve around either finding novel ways to solve problems or creating functional designs and solutions.[8,9] These definitions differ from creativity in an artistic sense, as the solutions and designs must be viewed as purposeful or functional in engineering and engineering education contexts.[8]

Functional creativity has been measured by teacher observations[10] and self-report questionnaires.[11] However, these measures do not account for person-context interactions. In this study, which is a beginning attempt to explore person-context interactions in engineering, creativity was examined as a self-concept composed of three constructs: creative self-efficacy, creative identity, and creative expectations. A cross-sectional study of first-year and senior engineering students was conducted to investigate the three constructs that measure creative self-concept.

Gender differences in how creative self-concepts differ from first-year to senior year were also explored as previous research has demonstrated differences in creativity between males and females.[12] For instance, Felder, Felder, Mauney, Hamrin, & Dietz[13] found that female students desired and expected more creative work at the start of engineering courses than males, but rated their own creative problem solving ability significantly lower than males at the end of the course. However, the self-ratings may not have accurately reflected performance on these tasks. In another study, Charyton & Merrill[11] found that female engineering students actually scored higher on post-test creative design tasks than males even though there were no gender differences in creativity at the beginning of the activity. The results from these studies indicate that engineering courses and programs may influence the perception of creativity and the development of individual creative abilities differently by gender.

Creativity Research in Engineering Education

The importance of fostering creativity in engineering education has recently been championed by many stakeholders. The National Academy of Engineering[14] released a report of the *Engineer of 2020* project, which described the aspirations and attributes of the future engineering graduates. The committee stated that graduates need to possess traits such as “strong analytical skills, creativity, ingenuity, professionalism, and leadership” (p. 59).[14] The accreditation criteria for engineering programs also references the importance of developing creativity by stating: “The engineering sciences have their roots in mathematics and basic sciences but carry knowledge further toward creative application” (Criterion 5. Curriculum).[15] Additionally, several scholars have stressed the need to design creativity-driven pedagogies in engineering education to help future engineers cope, adapt, and succeed in their future careers.[16-19,]

Given the national initiatives and near universal agreement of the importance of creativity and innovation in engineering, the lack of research on creativity and the creative process with engineering students is surprising. In a content analysis of articles from primary engineering education sources from 2006 through 2011, Zappe, Mena, and Litzinger found just 16 articles that used the words “creative” or “creativity” in the title.[19] In addition, many of these articles were not empirical research on creativity in engineering students, but were rather descriptions of classroom activities that had the intention of impacting students’ creativity. While these classroom-based studies clearly illustrate that creativity is a skill that can be increased with practice and should not be considered as a wholly innate and unlearnable trait, past research offers little insight into engineering students’ perceptions of creativity in engineering.

Some evidence suggests that a disconnect exists in engineering between the number of opportunities faculty perceive there are for students to exercise their creativity and the number of opportunities student perceive. In a survey of undergraduates, Kazerounian and Foley[20] found that engineering students felt that their instructors do not value creativity and that opportunities to be creative in their courses were lacking. However, engineering faculty members reported that they valued creativity in their students, but did not perceive their students to be particularly creative. Interestingly, these perceptions differed depending on the academic discipline (i.e.

engineering, science, and humanities), which led the authors to argue that "[c]reativity is not valued in contemporary engineering education" (p. 762).[20]

Lai, Roan, Greenburg, & Yang[21] suggest that engineering education classes may actually impede creative, specifically divergent, thinking. The authors argue that engineering students are trained to think and define problems in a certain way, as defined by their particular specialty. This effect can also be exacerbated by providing too much structure in design projects and preventing students from reflecting on how they proceeded through the design process. Therefore, programs that do not specifically seek to increase and foster creativity may negatively impact students' perceptions of their own creativity.

Clearly, more research needs to on focus students' perception of creative in engineering education programs. Little is known about how these self-perceptions of creativity change as students' progress through the engineering curriculum. Additionally, little is known about how these perceptions differ by gender.

Self-Perceptions of Creativity

Recent theories on creativity developed within industrial/organizational psychology conceptualize creativity as "a complex person-situation interaction."[22]The potential for creative behavior stems from aspects of both the individual and the situation. Individual aspects include biographical variables of the individual, such as gender, and other attributes of the person, including knowledge, skills, and abilities (KSAs). Characteristics of the situation also impact the extent to which creative behavior occurs. The individual and situational characteristics interact to impact the potential for creative behavior. Although this theory was originally developed for a workplace setting, the model can be applied to a classroom setting where an instructor can develop activities that either suppress or promote student engagement in creative behaviors. Whether or not an individual student engages in creative behaviors is also driven by personal characteristics. Possessing higher levels of certain traits may lead to a greater likelihood of creative performance, but only if the environment is supportive. In the engineering education field, Charyton and colleagues[11,23] introduced a similar model in which the creative process is impacted by the environment (i.e. classroom or an industrial setting) and personal attributes (i.e. creative personality, creative temperament, and cognitive risk tolerance). Three individual attributes that could potentially impact students' likelihood of engaging in creative behavior are creative self-efficacy, creative personal identity, and creative expectations.

Bandura[24] defined self-efficacy as "the conviction that one can successfully execute the behavior required to produce" a particular outcome in a domain (p. 193). Tierney and Farmer[25] introduced the construct of creative self-efficacy in 2002, which they define as "the belief one has the ability to product creative outcomes" (p. 1138). Tierney and Farmer[25-26] found that creative self-efficacy is predictive of creative performance.

A second creative self-construct is creative personal identity, introduced by Jaussi, Rendel, and Dionne.[27] According to Jaussi and colleagues, personal identity is "one that an individual holds critical to his or her self-concept" (p. 248).[27] The personal identity is generated through personal experiences, is constructed over a period of time, and reflects the importance the individual places on a particular category. Jaussi and colleagues extend this definition of personal identity to the construct of creativity: “Creative personal identity is comprised of the overall importance a person places on creativity in general as part of his or her self-definition…” (p. 248).[27]

The final creative self-concept explored in this study concerns creative expectations[26,28]. Originally conceptualized for workplace settings, supervisory creative expectations refers to an employee’s perceived expectations that they be required to do creative work by their supervisor as part of their job. For this study, we re-conceptualized the construct to be perceived expectations from students’ instructor that they need to be creative. An example item is “There is an expectation that I do creative work in my classes.”

This paper focuses on the impact of engineering curricula on these three aspects of the creative self-concept: creative self-efficacy, creative identity, and creative expectations. The overall purpose of the paper will be to examine how scores on scales measuring these constructs differ between first-year and senior students and between female and male students.

Methods

Data collection procedure

A cross-sectional study was conducted in order to examine differences in students’ self-perceptions of creativity during the first and senior years. The research study occurred at a large, mid-Atlantic research-oriented university. In Fall 2012, first-year students who intended to major in engineering were asked to participate in the study. The students had just started their undergraduate studies approximately two weeks prior to receiving an invitation to participate. In April 2013, senior engineering students, two weeks away from graduation, were also invited to participate.

The creativity study was embedded in a larger study of the professional skill set in engineering students. One of the primary purposes of the larger study was to examine students’ perceptions of global readiness. Because of the unique experiences of international students regarding global readiness and because the larger study context drove decisions about data collection methods, only resident students (US citizens or permanent residents) were invited to participate. In addition, the overall study design involved only surveying first-year and senior students, for a total of four years. Sophomores and juniors were not invited to participate in the study, not because their data would not be informative, but primarily to reduce the number of surveys administered to students in the College. Oversurveying is a large concern of the College of Engineering and thus, the decision was made to only survey first-year and senior students. Data was collected via an online survey.

Participant demographics

Of the 2,596 first-year students who were invited to complete the survey, a total of 865 participated for a response rate of 33.3%. Of the 1,316 seniors who were invited to participate, a total of 378 participated for a response rate of 28.7%. The proportion of female students at each class level is similar with 199 female first-year students (23%) and 93 female seniors (24.6%).

The large difference in numbers invited to participate for first year and senior students can be attributed to three factors. First, not all first year students who intend to be engineering majors end up at the main campus graduating from the College of Engineering. Some stay at their "home campuses" for other programs including some engineering degrees which are outside the College of Engineering at the main campus. It is unknown who will eventually come to the main campus to major in engineering. Secondly, the number of first year students intending to major in engineering continues to increase each year. Finally, some students do not persist in engineering and change their intended major to one outside of the College. The intended majors of the first year students are presented in Table 1 and the majors of the seniors are presented in Table 2.

Table 1: Frequency count of the first year students' majors

Major	Female	Male	Total
Architectural Engineering	21	29	50
Aerospace Engineering	15	72	87
Bioengineering	23	31	54
Biological Engineering	3	2	5
Chemical Engineering	31	59	90
Civil Engineering	20	66	86
Computer Engineering	7	45	52
Computer Science	10	44	54
Electrical Engineering	10	61	71
Engineering Science	6	3	9
Industrial Engineering	8	9	17
Mechanical Engineering	32	189	221
Nuclear Engineering	4	31	35
Other	9	25	34
Total	199	666	865

The majority of students who participated intended to complete an engineering major offered at the university's main campus. The students with "other" listed either intend to major in an engineering major only offered at one of the university's campus locations or, in a few cases, were listed in the College of Engineering pool but had since changed their major. Some gender differences were apparent when examining frequency of participation in the majors. For instance, 29% of male participants were enrolled in mechanical engineering, while only 14% of female participants were mechanical engineering majors. Bioengineering (4.2% of males and 11.3% of females), chemical engineering (8.6% of males vs. 16.8% of females), electrical engineering (9.1% of males vs. 4.8% of females), and nuclear engineering (4.7% of males vs. 2.4% of females) also had fairly large gender differences in terms of response rate. These differences in gender are attributed to a few different factors. First, many of the engineering majors have enrollment controls, so many students are often not able to get their first major of choice. A second reason could be due to attrition in that some students do not persist in engineering. Third, students may change their intended major as they become more informed as to their choices within engineering.

Table 2: Frequency count of the seniors' majors

Major	Female	Male	Total
Aerospace Engineering	4	23	27
Architectural Engineering	8	11	19
Bioengineering	10	9	19
Biological Engineering	7	5	12
Chemical Engineering	18	23	41
Civil Engineering	6	32	38
Computer Engineering	0	9	9
Computer Science	2	17	19
Electrical Engineering	4	26	30
Engineering Science	0	12	12
Industrial Engineering	21	18	39
Mechanical Engineering	10	86	96
Nuclear Engineering	3	14	17
Total	93	285	378

Since first year students had only completed a few courses, comparing their undergraduate GPA with seniors is not feasible. However, SAT scores were collected from both samples and are presented in Table 3. In both groups, males had lower SAT Writing and Verbal scores than females. First year males had a higher Verbal Math SAT than females, but that difference was minimal in seniors with females reporting slightly higher scores. A MANOVA did not find a significant multivariate effect for the interaction of student level and gender on SAT scores (Hotelling's $T(3,1235)=0.97$, $p=0.041$). Senior engineering students had significantly higher SAT scores than first year students in all categories [Hotelling's $T(3, 1235) = 13.48$, $p<0.001$; Writing $F(1,1237)=19.02$, $p<0.01$; Verbal $F(1,1237)=18.57$, $p<0.001$); Math $F(1,1237)=40.50$, $p<0.001$]. Again, these differences are likely due to the fact that some students will leave engineering and change their major to one outside the College. It is likely that students with lower math ability or who struggle in their courses, which could be correlated with their SAT scores, are more likely to leave the College for another major.

Table 3: Students' SAT scores

			N	Mean	SD
Freshman	SAT Writing	Male	666	549.41	102.76
		Female	199	577.64	95.37
		Total	865	555.90	101.75
	SAT Verbal	Male	666	559.83	95.81
		Female	199	570.20	94.89
		Total	865	562.22	95.64
	SAT Math	Male	666	625.85	95.13
		Female	199	607.34	82.89
		Total	865	621.59	92.74
Senior	SAT Writing	Male	283	570.04	87.44
		Female	93	617.65	74.66
		Total	376	581.81	86.83
	SAT Verbal	Male	283	581.13	87.76
		Female	93	606.14	68.11
		Total	376	587.32	83.95
	SAT Math	Male	283	656.19	85.47
		Female	93	658.72	62.66
		Total	376	656.81	80.36

Instruments

The students received three scales relating to creativity: the Creative Self-Efficacy Scale,[25] the Creativity Identity Scale,[27] and an adapted version of the Creative Expectations Scale.[28] Subscale scores were calculated for each student by adding the scores for each item, reverse coding negatively worded items.

The creative self-efficacy scale consists of three items on a 7-point Likert-type. Using the full dataset for this study, Cronbach's alpha was calculated to be 0.778. This alpha is slightly lower than that reported by Tierney and Farmer who obtained an alpha of 0.83 to 0.87 in their 2002 study.[25] The creative identity scale consists of four items on a 5-point Likert-type scale. Using the full dataset, Cronbach's alpha was calculated to be 0.85, just under the 0.89 alpha reported by Jaussi, et al.[27] The creative expectations scale consists of three items on a 5-point Likert-type scale. The alpha calculated using the full dataset equaled 0.83, slightly lower than the 0.91 alpha obtained by Farmer, et al.

Results

Table 4 provides the descriptive statistics for each of the scales used in the study. For each scale, a two-way analysis of variance (ANOVA) was conducted to measure whether the scale score (the independent variable) was impacted by the dependent variables of gender and year in school.

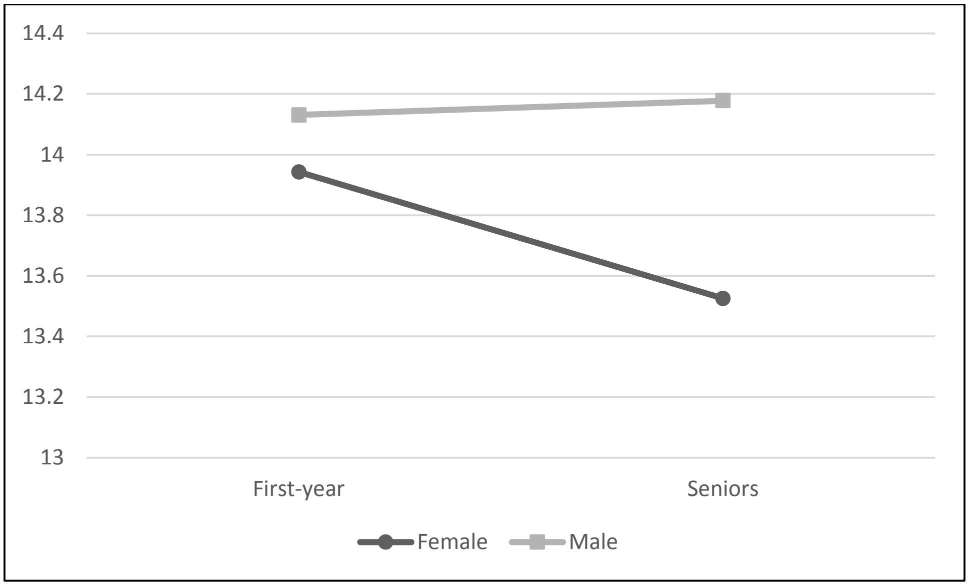
Table 4: Descriptive statistics for scales used in study

		First Year Students				**Seniors**			
	Scale	**Obs. Min**	**Obs. Max**	**Mean**	**SD**	**Obs. Min**	**Obs. Max**	**Mean**	**SD**
Males	Creative self-efficacy	3	18	14.13	2.24	6	18	14.17	2.44
	Creative identity	4	20	15.04	3.02	4	20	14.92	3.36
	Creative expectations	3	15	10.48	2.04	3	15	9.70	2.19
Females	Creative self-efficacy	7	18	13.94	2.16	8	18	13.52	2.23
	Creative identity	4	20	15.54	3.25	6	20	14.41	3.35
	Creative expectations	6	15	10.82	2.04	3	15	9.76	2.11

Creative self-efficacy

The results showed a significant main effect for gender on creative self-efficacy scores [$F(1,1079) = 5.688$, $p = 0.017$]. The main effect of class year was not significant [$F(1,1079) = 5.724$, $p = 0.297$]. The results suggest that female students have a lower creative self-efficacy score at both the first and senior years as compared to males, as shown in Figure 1. While the interaction between gender and year level is not significant [$F(1,1079) = 9.023$, $p = 0.187$], the observed mean difference between males and females is larger at the senior level as compared to the first-year level. The average scores for males are relatively flat between the first and senior years while the scores for females drop. In summary, the statistical analysis shows that creative self-efficacy scores are different for males versus females across both years. There is no statistically significant difference by year and no significant interaction between year and gender.

Figure 1: Estimated marginal means plot for creative self-efficacy score



Creative identity

For the creative identity scale, the results show a significant interaction between gender and class year [$F(1,1082) = 4.346$, $p = 0.037$]. Additionally, the main effect for class year was significant [$F(1,1082) = 6.564$, $p = 0.011$]. However, the main effect for gender was not significant [$F(1,1082) = 0.001$, $p = 0.981$]. An examination of the means plot (shown in Figure 2) shows that female students in their first year have a higher score on the creative identity. However, senior women have lower scores on this scale as compared to male students. The scores of male students remain relatively flat from the first-year to the senior year. In summary, the results of the statistical analysis support that creative identity scores are lower for seniors of both genders as compared to first-year students; female seniors' scores are markedly lower than males.

Creative expectations

For the creative expectations scale, the result indicates a significant main effect for class year [$F(1,1074) = 63.961$, $p < 0.000$]. The main effect for gender [$F(1,1074) = 14.10$, $p = 0.102$] and the interaction [$F(1,1074) = 0.505$, $p = 0.757$] are not significant. As shown in the means plot in Figure 3, scores for both men and women are higher for first-year students than senior students. In summary, creative expectations are significantly lower at the senior year as compared to the first-year. The decreases in scores are very similar for both males and females.

Figure 2: Estimated marginal means for creative identity score

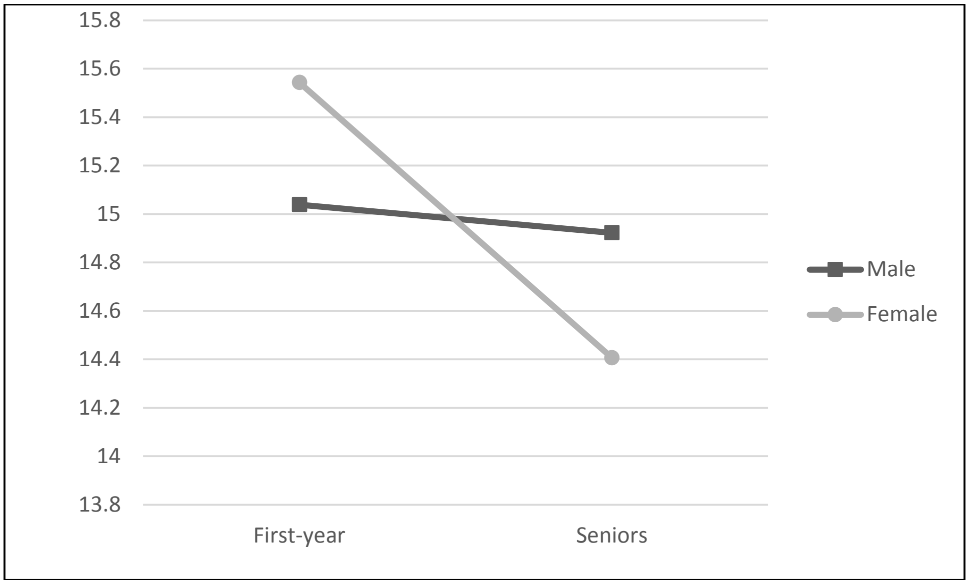
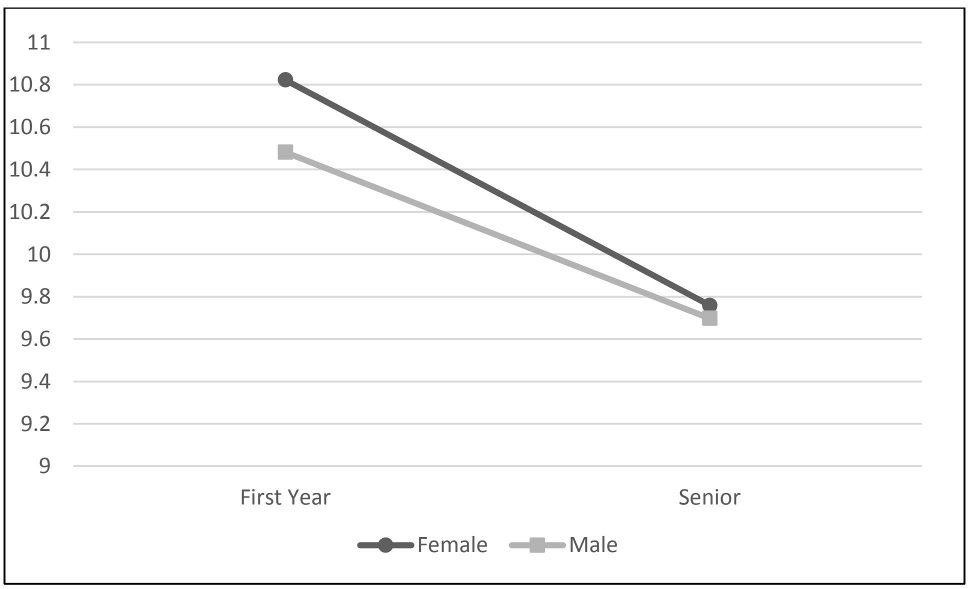


Figure 3: Estimated marginal means for creative expectations score



Discussion

The study examined creativity from a new perspective in engineering education by measuring three constructs related to creative self-concept. While informative, the results of this study are unfortunately somewhat discouraging regarding engineering students' creative self-concepts, particularly concerning gender differences. First, even though overall creative self-efficacy did not change over time, the results show that female students at both the first and senior years have less confidence in their ability to be creative individuals. Furthermore, although the trend was not significant, senior females may have less creative self-efficacy than first-year females. A considerable amount of research has shown that differences in the levels of confidence of males and female working in STEM fields[29], and this study expands that research to creative endeavors. Further research and instructional practices should attempt to address and correct these gender differences and encourage all students to engage in creative activities.

However, confidence and self-efficacy may decrease over time as individuals are better acclimated to the expectations and challenges of a field because they are able to more accurately evaluate their individual ability[30]. Therefore, it is important to examine other self-concepts. The two other constructs measured in this study, creativity identity and creative expectations, provide further insight into how the person and environmental interaction influences creative self-concept.

The results indicated that overall creative identity is lower for seniors than for first-year students. The results suggest that advanced students may not hold the belief that creativity is an essential component needed in engineering. Interestingly, the effect depends on gender. In the first year, females have a stronger creative identity than male students. However, senior female students have a weaker creative identity than male students. The interaction may be explained by the creative expectations as students may become aware of the need to alter their creative identity in accordance with the expectations of the field[20].

Unsurprisingly, both males and females in their senior year feel that their instructors have lower expectations for creative behaviors as compared to first-year students. First year females have higher creative expectations than male first year students, but both have similar expectations as seniors. The steeper decline in the expectations of female creative expectations may contribute to a decrease in creative identity over time.

Limitations

The primary limitation of this study is that it is cross-sectional, rather than longitudinal. Therefore, we must be cautious in interpreting the data as changes in creative self-concept that occur as students progress through the curriculum. The population of students entering their first year may be different than those at the senior year. Differences in the samples were confirmed by examination of their average SAT scores. Students just starting their studies may be overly optimistic and may potentially base their responses on their high school experiences rather than experiences as an undergraduate. Another limitation is that only domestic, resident students were included in the study, due to constraints of the overall study purpose. As mentioned in the methods, these study constraints also limited the authors' ability to only study first-year and senior students. Other researchers or future studies may want to examine growth across the four years, by collecting data cross-sectionally from all undergraduate levels or by tracking students longitudinally as they progress throughout the curriculum.

Another threat to the validity of these findings is that a proportion of students in the first-year leave engineering. Who are the students that leave engineering? The literature points to factors such as deficits in necessary knowledge or skills[31] as well as psychological structures such as attitudes towards engineering[32] and motivation[33]. No studies have examined whether there is a relationship between creative self-concept and engineering persistence. However, one can hypothesize that students with a strong creative identity who feel they are not given opportunities to engage in creative activities may not persist within engineering. Alternatively, it is possible that engineering program hinders the development or expression of creativity in the students that do persist and progress. A longitudinal study would provide insight into how the engineering curriculum impacts students' creative self-concepts and whether creative self-concepts impact persistence. The authors are currently planning to survey the first-year students who participated in this study when they are finishing their senior years. This will allow for further examinations on the characteristics of students who leave engineering and whether any relationship exists between persistence and creative self-concepts.

Most analytical and technical engineering courses do not require students to engage in the creative process.[34] What can faculty members do to encourage creative behaviors from their students? Runco[35] suggests that, first, instructors need to provide opportunities for their students to practice creative thinking. Second, instructors need to value and appreciate students' creative efforts, perhaps by including this in grading mechanisms. Finally, instructors themselves need to model creative behaviors. Faculty development opportunities, such as those described by Zappe, Litzinger, and Hunter,[36] can help to identify activities and remove possible barriers to integrating creativity into engineering courses.

Conclusion

Despite the limitations, the results from this study provide some evidence to support the claims made by Lai, et al.,[21] who suggested that engineering programs are not doing enough to support or emphasize creative thinking. These findings are disappointing given the importance and prominence of creativity in current engineering education objectives and research.[14-17] The current study examined creativity in engineering education from a new perspective by measuring creative self-concepts. The results indicated that two measures of creative self-concepts, creative expectations and creative identity, were lower in seniors than first years, which reinforces Kazerounian and Foley's[20] assentation that students perceive that engineering faculty and programs do not value creativity. Therefore, there is a discrepancy between the prioritization of creativity in the academic literature and the impressions that are being made on students in the classroom. Future research and pedagogy should continue to examine and attempt to positively influence these constructs and students creative self-concept in engineering courses and programs.

References:

1. Torrance, E. P. (1963). Creativity, National Education Association. Washington, D.C.
2. Boden, M. A. (Ed.). (1996). *Dimensions of creativity*. MIT Press.
3. Getzels, J. W., & Jackson, P. W. (1962). Creativity and intelligence: Explorations with gifted students.
4. Larson, M.C., B.H. Thomas, and P.O. Leviness. 1999. Assessing creativity in engineers. *American Society of Mechanical Engineers, Design Engineering Division (Publication)* DE 102: 1–6.
5. Mahboub, K. C., Liu, Y., Chandraratna, S. & Portillo, M. B. (2003). Creativity in Design: A cross disciplinary approach In *Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition*.
6. Sternberg, R. J. (Ed.). (1999). *Handbook of creativity*. Cambridge University Press.
7. Csikszentmihalyi, M. 1999. Implications of a systems perspective for the study of creativity. In *Handbook of Creativity*, ed. R.J. Sternberg. Cambridge, MA: MIT Press.
8. Cropley, D., and A. Cropley. 2005. *Engineering creativity: A systems concept of functional creativity*. Mahwah, NJ: Lawrence Erlbaum Associates
9. Ishii, N., and K. Miwa. 2005. Supporting reflective practice in creativity education. In *Proceedings of the 5th conference on Creativity & Cognition*. London, England.
10. Buelin-Biesecker, J., & Wiebe, E. N. (2013). Can Pedagogical Strategies Affect Students' Creativity? Testing a Choice-Based Approach to Design and Problem-Solving in Technology, Design, and Engineering Education. *Proceedings of the 2013 American Society for Engineering Education Annual Conference & Exposition*.
11. Charyton, C., & Merrill, J. A. (2009). Assessing general creativity and creative engineering design in first year engineering students. *Journal of engineering education*, 98(2), 145-156.
12. Baer, J., & Kaufman, J. C. (2008). Gender differences in creativity. *The Journal of Creative Behavior, 42(2),* 75-105.
13. Felder, R. M., Felder, G. N., Mauney, M., Hamrin, C. E., & Dietz, E. J. (1995). A longitudinal study of engineering student performance and retention. III. Gender differences in student performance and attitudes. *Journal of Engineering Education*, 84(2), 151-163.
14. National Academy of Engineering (2004). *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, D.C.: National Academies Press.
15. ABET, Criteria for Accrediting Engineering Programs, Effective for Evaluations During the 2015-2016 Accreditation Cycle, ABET Engineering Accreditation Commission, Baltimore, MD.
16. Amato-Henderson, S., Kemppainen, A., & Hein, G. (2010). *Assessing creativity in engineering: for a working definition and valid assessments of domain specific creative cognitive ability.* American Society for Engineering Education.
17. Fleisig, R., Mahler, H. & Mahalec, V. (2009). *Engineering design in the creative age.* Paper presented at American Society for Engineering Education, DEED Poster Session, 2009 Annual Conference and Exposition.
18. Walker, V., Jensen, D., Crider, K., Weaver, J., Wood, K., & Maixner, M. (2010). Effects of an early prototyping experience: Can design fixation be avoided? Paper presented at American Society for Engineering Education, DEED Potpourri, 2010 Annual Conference and Exposition.
19. Zappe, S. E., Mena, I., Litzinger, T. A. (March, 2013). Creativity is not a purple dragon. Paper presented at the annual conference of the National Collegiate Inventors and Innovators Alliance, Washington, D.C.
20. Kazerounian, K., and S. Foley (2007). "Barriers to Creativity in Engineering Education: A Study of Instructors and Students Perceptions." *Journal of Mechanical Design* 129:761-768.
21. Lai, J. Y., Roan, E. T., Greenberg, H. C., & Yang, M. C. (2008). Prompt versus problem: Helping students learn to frame problems and think creatively. In *Third International Conference on Design Computing and Cognition* (p. 2nd).
22. Hunter, A. T., Cushenbery, L. & Friedrich, T. (2012). Hiring an innovative workforce: A necessary yet uniquely challenging endeavor. *Human Resource Management Review*. 22(4): 303-322.
23. Charyton, C., Jagacinski, R. J., & Merrill, J. A. (2008). CEDA: A research instrument for creative engineering design assessment. *Psychology of Aesthetics and Creativity in the Arts.* 2(3): 147-154.
24. Bandura, A. (1977). Self-efficacy. Toward a unifying theory of behavioral change. *Psychological Review.* 84, 191-215.
25. Tierney and Farmer (2002). Creative self-efficacy: Its potential antecedents and relationship to creative performance. *Academy of Management Journal.* 6, 1137-1148.

26. Tierney, P. & Farmer, S. M. (2011). Creative self-efficacy development and creative performance over time. *Journal of Applied Psychology.* 96(2): 277-293..
27. Jaussi, K. S., Randel, A. E., & Dionne, S. D. (2007). I am, I think I can, and I do. The role of personal identity, self-efficacy, and cross-application of experiences in creativity at work. *Creativity Research Journal.* 19(2-3), 247-258.
28. Farmer, S. M., Tierney, P., & Kung-McIntyre, K. (2003). Employee creativity in Taiwan: An application of role identity theory. *Academy of Management Journal.* 46(5): 618-630.
29. Besterfield-Sacre, M., Moreno, M., Shuman, L. J., & Atman, C. J. (2001). Gender and Ethnicity Differences in Freshmen Engineering Student Attitudes: A Cross-Institutional Study*. *Journal of engineering Education*, *90*(4), 477-489.
30. Gist, M. E., & Mitchell, T. R. (1992). Self-efficacy: A theoretical analysis of its determinants and malleability. *Academy of Management review*, *17*(2), 183-211.
31. Zhang, G., Anderson, T. J., Ohland, M. W., & Thorndyke, B. R. (2004). Identifying factors influencing engineering student graduation: A longitudinal and cross-institutional study. *Journal of Engineering Education.* 93(4): 313-320.
32. Besterfield-Sacre, M., Atman, C. J., & Shuman, L. J. (1997). Characteristics of freshman engineering students: Models for determining student attrition in engineering. *Journal of Engineering Education.* 86(2): 139-149.
33. French, B. F., Immekus, J. C., & Oakes, W. C. (2005). An examination of indicators of engineering students' success and persistence. *Journal of Engineering Education.* 94(4): 419-425.
34. Stouffer, W.B., J.S. Russell, and M.G. Oliva (2004). "Making the Strange Familiar: Creativity and the Future of Engineering Education." Paper presented at the Annual Conference of the American Society for Engineering Education, Salt Lake City, UT.
35. Runco, M. A. (2006). *Creativity. Theory and themes: Research, Development, and Practice.* PA: Elsevier.
36. Zappe, S. E., Litzinger, T. A. & Hunter, S. T. (2012). Integrating the creative process into engineering courses: Description and assessment of a faculty workshop. Paper presented at the Annual Conference of the American Society of Engineering Education, San Antonio, TX.