Student experiences of learning in creativity-integrated engineering courses

The future of engineering demands an interdisciplinary workforce whose training extends to a broad understanding of increasingly complex systems which enables engineers to design, test, and deploy meaningful solutions to urgent problems. Due to this need, it is widely agreed that creativity is an important trait for engineers to possess (Berg et al., 2012). Engineering educators and researchers have practiced methods and strategies to foster their students' creativity, many of which are traditionally implemented in university engineering classes. For example, Kazerounian and Foley (2007) developed and implemented their *Ten Maxims of Creativity in Education*. Their research has found that these maxims are largely absent from engineering classes. Instead, engineering classes tend to stifle creativity (Cropley, 2015) and provide limited opportunities to think creatively (Daly et al., 2014).

To address this problem, we developed an approach towards engineering education that teaches the foundations of engineering and innovation through a program that we call the *Creativity Academy*. The *Creativity Academy* is a two-week workshop that provides educational programming designed to teach and support engineering educators in integrating evidence-based creativity training methods into their classrooms. In the summer of 2020 and 2021, ten engineering faculty members participated in the *Creativity Academy*. With the goal of understanding how participation in the *Creativity Academy* impacted classroom practices of engineering faculty, we conducted focus group interviews with their students.

The following research questions guided our study:

- RQ1: What learning activities did students experience in classes from instructors who completed the *Creativity Academy*?
- RQ2: What activities encouraged or discouraged creativity from engineering students in classes from instructors who completed the *Creativity Academy*?

Methodology

The purpose of this study is to examine how students perceived the creativity-fostering effectiveness of the methods used by their instructors. Findings from this study will provide engineering educators and researchers with insight and solutions to improve their teaching skills relative to embedding opportunities for students to engage in acts of creativity.

Participants

Participants were recruited via email from the student rosters of the 10 engineering courses taught by instructors who completed the *Creativity Academy*. We conducted one focus group for each course with between one to four students per class (see Table 1 for more details).

Data Collection

Data was collected from fall 2020 through spring 2022. Each focus-group interview was conducted no earlier than the start of the 13th week of each semester. All focus-group interviews were conducted via Zoom and recorded for future analysis. During the interview, we primarily focused on understanding (1) the activities/assignments that students experienced (2) how classroom activities/assignments encouraged student creativity, and (3) how activities/assignments hindered student creativity.

Data Analysis

Recordings were transcribed and imported into NVivo 2020 (QSR International Pty Ltd, 2020). To analyze the data we conducted a six-step thematic analysis process (Braun & Clarke, 2006). Responses were categorized into different codes such as "discussion," "lectures," or "creativity exercises" for in-class activities and "group project," "open-ended questions," or "problem-based homework" for assignments. Other codes include "allow not much exploration," "do things in the same way," or "grading methods" for why engineering classes do not encourage creativity. These codes were later examined and grouped into different themes such as "in-class activities," "after-class activities," or "activities encouraging creativity."

Results

RQ1: What learning activities did students experience in classes from instructors who completed the *Creativity Academy*?

In-class activities

In regards to in-class activities, students reported that lectures and discussions were the two most frequently experienced activities. In one example, P28 described his instructor's in-class activities as being primarily, "*a lot of demonstrations on the board…He will have all the formulas down. He would draw like maps… to help us understand*." However, it was reported that some instructors who attempted to innovate their approach to lecturing. For example, "*He [the instructor] embeds all of like little two to three minute videos within his lecture … it's useful that he puts the videos that like simulate certain things* (P26)."

Further, students widely stated that instructors utilized discussion-based activities in their engineering courses. In one example, P01 explained that his instructor would, "*break us into our own little chats, and then we'd have like a minute and a half or so to come up to like answer a question*." It was stated that these discussions would often lead to positive outcomes for students. For instance, P14 stated, "*I think the discussion is very well … and I think it encourages ... like community building … some people did go out to the farmers' market a week or two ago, together with people in the class*."

Of particular interest was the use of *creativity exercises* (e.g., alternative uses of an object) by instructors. Students indicated that these creativity exercises motivated them, "*once we were* *given like a duster, and we had to figure out different ways we can use this duster* (P17)" and "*we stand in a circle, and just tell each other we failed, how we failed, and what we learned from the failure* (P23)." Many participants felt amazed because "*That's something that I haven't had in another class*. (P09)" They believed that these activities could help them "*critically/creatively think about maybe completely random things that could be used for [creation]* (P27)."

After-class activities

In regards to after-class activities, students reported that problem- and project-based assignments were the most common after-class activities and they were either done individually or done in a group. In one example, an instructor assigned a project that required students to "*incorporate the modules that we are learning into the project* (P06)." In line with promoting creativity, another student said they were required to "*come up with multiple designs, find different ways to evaluate them, and then critique your designs as well* (P09)." It was also reported that some instructors would encourage students to present their classroom projects for international competitions such as to "*design problems for AICHE [American Institute of Chemical Engineers]* (P16)." Lastly, many students reported that they were assigned "*a lot of reading"* (P12) throughout the semester as well as a range of multimedia content such as pre-recorded class videos and some "*really interesting TED videos* (P12)."

RQ2: What activities encouraged or discouraged creativity from engineering students in classes from instructors who completed the Creativity Academy?

Activities Encouraging Creativity

Students overwhelmingly stated that their creativity was encouraged by instructors who embraced free exploration, collaboration, and the open exchange of ideas in their classrooms. Students also commented that having opportunities to reflect and to "*make connections from our course to other disciplines* (P11)" helped them to think more creatively. Participants believed that being provided with "*hands-off approaches"* by instructors *"really make us think* (P10)" and open-ended questions that "*encourage you to propose multiple solutions* (P05)" were important to fostering their creativity. Participants also stated that they were able to be more creative when instructors provided them with opportunities to fail. For example, some participants suggested that instructors should "*not penalize us too much if, like, we aren't on the right track on those open-ended questions* (P26)." Lastly, participants identified collaboration as an essential method to develop creativity because "*work with other students, you get different ideas that you may not have thought of. Bringing those together, you come up with better things* (P28)."

Activities Discouraging Creativity

As for why some students think their engineering classes do not encourage creativity, many reasons are opposite to what we have presented in the paragraphs above. For example, participants stated that they have rarely experienced creativity exercises in engineering classes because "*In classes, teachers kind of want you to do things a set way or learn things a set way* (P03)" and "*it's [engineering is] very science-based, very mathematical, very repetitive. Like, it's* *things that you can replicate over and over again. You don't really need an aspect of creativity to get to those solutions* (P20)" As a result, participants perceived their homework as " *always given problems, and we've always come to a solution, and if we don't get to that final solution, then the answer was wrong, or we've like went off somewhere* (P18)." Furthermore, it was stated that some instructors might seemingly encourage students to take risks in coming up with homework solutions, but when they graded it their feedback was in contrast to this perspective with one student saying, "*you don't know what the teacher is really looking for* (P19)."

Discussion & Conclusion

Many findings from this study relative to students' perceptions of in-class activities and homework or assignments align with previous research findings. For example, students' experiences in engineering class discussions is backed up by prior research finding that engaging in peer discussion improves students' reasoning and problem-solving abilities (Lewin et al., 2016). Students held that engineering classes and homework were highly mathematics and formula-based, which made the classes and homework rigid with little space for divergent thinking. This perception is echoed by other research that suggests engineering usually looks for one best solution through comparison and evaluation (Baillie & Fitzgerald, 2000; Daly et al., 2014) instead of multiple solutions.

Despite what we have already known, our study has still provided us with some new knowledge on why engineering classes do not encourage creativity. For example, students believed that engineering problem-solving processes are usually straightforward and convergent, so they believed that creativity is not needed in this process. Some students stated that instructors were inconsistent between the homework grading policy and what they claimed in the class, and thus students were cautious in taking risks to find multiple solutions in homework or assignments to avoid penalties on grades.

Students' perceptions reflect a problem in engineering education – the lack of exposure to creativity-fostering opportunities. Though ensuring the effective delivery of fundamental engineering knowledge to students is important, engineering educators may consider organizing more activities that encourage students to think and discuss in classes. In addition, engineering instructors should provide more open-ended problems that allow students to explore solutions to solve problems. The latter strategy has been considered effective in fostering creativity (Zhou, 2012). Meanwhile, for open-ended questions, engineering instructors need to be more tolerant of students' mistakes or different solutions compared to the one that instructors prefer.

Changes from Faculty Participation in the *Creativity Academy*

In regards to participation in the *Creativity Academy*, we found evidence that instructors are adapting their instructional materials to fit the needs of engineering students better. As previously mentioned, students reported that instructors were developing new methods to break up the monotony of lecture-based instruction such as embedding new media (e.g., short videos) to make their classes more creative. Importantly, findings indicate that instructors who completed the *Creativity Academy* began to host creativity fostering exercises in their classes to train students how to think divergently. Instructors also adapted their discussion protocols to better provide opportunities for students to collaborate and to build off of one another's ideas. This led some students to extend their in-class discussions outside of the class and to engage in authentic applied activities (e.g., attending a community building activity). These changes indicate that engineering instructors who completed the *Creativity Academy* have realized the importance of creativity in engineering education and are practicing different methods to foster it.

Connection to Conference Theme

In connection to the conference theme we present this work as "creating space for analysis and discussion designed to interrogate and advance methods and practices for just educational processes." In particular the *Creativity Academy* provides training to engineering faculty with a focus on encouraging a more positive learning experience for students by critically examining common practices in the field. We used this project as a way to "interrogate" previous researchers' findings about engineering classes and creativity and to train engineers to be creative and better positioned to be more deliberate in their practices to address complex real-world problems that often have broad implications and outcomes for marginalized communities. This project provides an example of education research that can inform and shape public policy and practice - especially in regards to providing a new interdisciplinary perspective to research that is often under-nuanced and decontextualized.

References

Baillie, C., & Fitzgerald, G. (2000). Motivation and attrition in engineering students. *European Journal of Engineering Education*, *25*(2), 145–155. https://doi.org/10.1080/030437900308544

Berg, H., Taatila, V., & Volkmann, C. (2012). Fostering creativity – a holistic framework for teaching creativity. *Development and Learning in Organizations*, *26*(6), 5–8. https://doi.org/10.1108/14777281211272242

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Cropley, D. H. (2015). Promoting creativity and innovation in engineering education. *Psychology of Aesthetics, Creativity, and the Arts*, *9*(2), 161–171. https://doi.org/10.1037/aca0000008

Daly, S. R., Mosyjowski, E. A., & Seifert, C. M. (2014). Teaching creativity in engineering courses: Teaching creativity in engineering courses. *Journal of Engineering Education*, *103*(3), 417–449. https://doi.org/10.1002/jee.20048

Kazerounian, K., & Foley, S. (2007). Barriers to creativity in engineering education: A study of instructors and students perceptions. *Journal of Mechanical Design*, *129*(7), 761–768. https://doi.org/10.1115/1.2739569

Lewin, J. D., Vinson, E. L., Stetzer, M. R., & Smith, M. K. (2016). A campus-wide investigation of clicker implementation: The status of peer discussion in STEM classes. *CBE—Life Sciences Education*, *15*(1), ar6. https://doi.org/10.1187/cbe.15-10-0224

QSR International Pty Ltd. (2020). *NVivo qualitative data analysis software* (New Release) [English]. QSR International Pty Ltd. https://www.qsrinternational.com/nvivo/home

Zhou, C. (2012). Teaching engineering students creativity: A review of applied strategies. *Journal on Efficiency and Responsibility in Education and Science*, *5*(2), 99–114. https://doi.org/10.7160/eriesj.2012.050205

Table 1

Demographic information of the focus groups and participants

Focus Group	Course Subject	Participant	Gender	Program	Degree
Group 1	Biomedical Engineering	P01	M	Engineering	Bachelor
		P02	M	Engineering	Bachelor
Group 2	Biological Engineering	P03	M	Engineering	Bachelor
		P04	M	Engineering	Bachelor
		P05	F	Engineering	Ph.D.
		P28	M	Engineering	Bachelor
Group 3	Biological Engineering / Food Science	P06	M	Engineering	Bachelor
		P07	F	Engineering	Bachelor
		P08	F	Engineering	Bachelor
Group 4	Biological Engineering	P09	M	Engineering	Bachelor
Group 5	Biomedical Engineering	P10	M	Engineering	Bachelor
Group 6	Environmental Science	P11	F	Engineering	Bachelor
		P12	F	Journalism	Bachelor
		P13	F	Interior Design	Bachelor

		P14	F	Interior Design	Bachelor
Group 7	Chemical Engineering	P15	F	Engineering	Bachelor
		P16	F	Engineering	Bachelor
		P17	M	Engineering	Bachelor
Group 8	Chemical Engineering	P18	M	Engineering	Bachelor
		P19	F	Engineering	Bachelor
		P20	M	Engineering	Bachelor
Group 9	Biomedical / Biological Engineering	P21	M	Engineering	Bachelor
		P22	M	Engineering	Bachelor
		P23	F	Engineering	Bachelor
Group 10	Biomedical / Biological Engineering	P25	F	Engineering	Bachelor
		P26	F	Engineering	Bachelor
		P27	M	Engineering	Bachelor