International Journal of Engineering Education Vol. 38, No. 2, pp. 564–580, 2022
Printed in Great Britain
0949-149X/91 $3.00+0.00

Investigating How Early-Career Engineering Faculty Perceive the Role Creativity Should Play in Engineering Education*

HAO HE
School of Information Science & Learning Technologies, University of Missouri, Columbia, MO, USA.
E-mail: hhv5b@mail.missouri.edu

JOHANNES STROBEL**
STEM & CS Education, Center for Education Research & Innovation, SRI International, Menlo, CA, USA.
E-mail: johannes.strobel@sri.com

SUZANNE BURGOYNE
Theatre Department, University of Missouri, Columbia, MO, USA. E-mail: BurgoyneS@missouri.edu

JOSHUA SABOORIZADEH
Theatre Department, University of Missouri, Columbia, MO, USA. E-mail: j.h.saboorizadeh@mail.missouri.edu

HEATHER K. HUNT
Department of Biomedical, Biological & Chemical Engineering, University of Missouri, Columbia, MO, USA.
E-mail: hunthk@missouri.edu

FERRIS MICHAEL PFEIFFER
Department of Biomedical, Biological & Chemical Engineering, University of Missouri, Columbia, MO, USA.
E-mail: pfeifferf@missouri.edu

Creativity is critical to engineering. This study aimed to understand engineering faculty members' perceptions of creativity and its relationship with engineering, their teaching philosophies, how they perceived their own and their students' creativity, and how their teaching philosophies affected their beliefs of incorporating creativity into engineering education. To accomplish our goal, we interviewed ten engineering faculty members and conducted a thematic analysis. The results indicated that the faculty members loved teaching and sharing knowledge, that they inherited their teaching skills from their teachers, or they learned them from colleagues or training camps, and that they enjoyed interacting with students, using group collaboration to accomplish assignments, and appreciating the moment students demonstrated insight and knowledge. Faculty members perceived creativity as something *new* and *beneficial to society*; they felt there was or should be a strong relationship between creativity and engineering. Most of them believed that they, as faculty members, were creative and that their students were creative in different ways. Their major concerns about directly integrating creativity into their teaching included that the integration might be time-consuming, that the evaluation would be complex, and that they lacked the knowledge, facilities, resources, and soft skills necessary to perform the integration. Implications of these findings are discussed.

Keywords: creativity; engineering education; teaching philosophies; creativity incorporation

1. Introduction

Researchers have defined creativity in different ways. However, traditionally, creativity is defined as appropriate ideas, work, or products that have novelty [1]. Definitions of creativity often involve terms such as "new," "novel," "creative thinking," "ability," "problem-solving," "imagination," or "innovation' [2, p. 189]. Taking this idea a step further, many researchers have suggested that, in addition to the emphasis on novelty, creativity also requires *value* or *utility* – that is, it must be useful to people and society [3]. Runco [4] further decomposed creativity into three components: transformation (the capacity for interpreting information from the world), intention (the capacity for consciously making changes for better outcomes), and discretion (the capacity for distinguishing originality from useless or non-sense ideas), while argued that the first component (transformation) is the most important. Alternatively, Ford and Harris [5] defined creativity as a thinking process that everyone has or everyone can gain through learning.

Beyond these definitions, creativity has been discussed in terms of its importance to specific fields or industries, such as engineering. For instance, researchers and engineers agree on the

** Corresponding author.

* Accepted 1 December 2021.

importance and significance of creativity in engineering (e.g., [6–8]), particularly in terms of innovation and technological advancement. There is a growing concern, however, that there appears to be an increasingly reduced emphasis on the teaching of creativity over time (e.g., [9]), resulting in several researchers expressing worry that engineers are becoming less creative [10], to the detriment of societal innovation. When asked why this could be happening, researchers who have reviewed engineering curricula have posited that engineering programs overemphasize technical skills to the detriment of creative thinking or creative actions [11]. This postulate leads to further questions about the content of engineering curricula and how it is implemented in a typical degree program. For instance, we still do not know how engineering instructors learn how to teach creativity, such as whether they have adequate pedagogical knowledge, skills, or tools to teach or integrate creativity into their classrooms, or what methods or skills they use; we are also not clear how they define creativity and how they think of their own and students' creativity. In addition, we even have no idea whether they believe that creativity can be taught and what, in their opinions, the relationship is between creativity and engineering. Addressing these questions may provide the key to understanding why researchers are consistently seeing decreases in engineers' creativity. We may also get insights into how to stop – and possibly reverse – this disquieting trend via faculty development and advances in classroom teaching practices.

To understand engineering faculty's perceptions of creativity, engineering, and the teaching of creativity, we propose the following research questions:

(1) What are engineering faculty members' teaching philosophies?
    (a) How do they perceive creativity?
    (b) How do they perceive their own and their students' creativity?
(2) How do they perceive the relationship between creativity and engineering?
(3) How do their teaching philosophies impact their understanding of incorporating creativity in engineering classes?

To answer these questions, we interviewed ten engineering faculty members regarding their creativity experiences in relation to engineering. The faculty members were from a single engineering department within the same AAU, land-grant, R1 university. If creative thinking and creative practices/skills are to be bolstered in engineering curricula, we must first start by considering how faculty members and instructors think about creativity in order for them to be more intentional in how they introduce creativity into their teaching practice. Thus, we hoped to find clues regarding why creativity and creative practices might be experiencing a downward slide in engineering programs to address this issue.

2. Literature Review

2.1 Creativity in Engineering

Many early discussions about creativity focused on creativity in artistic areas (e.g., art, music, dance, etc.), but those discussions gradually began to shift after the first human-made satellite was sent into space [12], resulting in significant increases in the number of studies of creativity in engineering.

Though some researchers found no significant correlations between creativity and engineering design outcomes [13], the mainstream view is that creativity is essential in engineering [14]. Creativity and engineering share a similar goal – to generate new and effective products or solutions to problems [9]. Concurrent engineering is a widely-used and effective engineering design approach in the industrial setting, but it does not help generate original ideas [15]. However, engineering education has not done enough to teach students how to generate or explore new ideas [16]. This issue has created a gap between the needs of industry and the content of engineering education. For example, Kazerounian and Foley [17] proposed the Ten Maxims of Creativity in Education to evaluate how instructors and students perceived creativity encouraged in their educational environments. The result was startling: engineering students' perceptions were absent in nine out of the ten maxims, suggesting that engineering students do not consider creativity an essential part of engineering.

So, what does "being creative" look like? In addition to thinking divergently, "being creative" includes being flexible, which means that education should let students feel comfortable when facing various non-linear, unknown situations [18]. To encourage flexibility, instructors need to develop a free and safe educational atmosphere [19].

In order to foster and encourage creativity in engineering educational environments, researchers explored several approaches. For instance, Thompson and Lordan [20] identified five core creativity tools: brainstorming (students propose as many ideas as possible without judgment), synectics (students use analogies and metaphors to explore problems for better solutions), morphological analysis (students decompose a problem into small parts and choose the best solutions for each part), brainwriting (students write their ideas down anonymously and then collect and evaluate all ideas), and checklists (students use a list of hint questions to promote creativity in problem-solving). They believed that correctly using these tools would develop engineering students' creativity. Gordy and Peary [21] used creative writing in a sociological way to develop students' creativity and posited that the method could be used in various fields or disciplines. In addition, since engineering students demonstrated no remarkable advantages in creativity compared to artistic students [22] and participating in creativity training substantially increased students' self-efficacy in engineering design [23], Pfeiffer and his colleagues [24] integrated creativity methods used in theatre programs into engineering education.

Beyond efforts to develop students' creativity, there have also been previous efforts to develop teachers' creativity. For instance, Davies [25] posited that the core of good teaching was a student's trust that his/her teachers would better prepare him/her for the future. He pointed out that, since the future is unpredictable, teachers had to "expose learners to new and innovative situations" (p. 69), and thus instructors' teaching approaches must be as creative as the approaches students are learning.

2.2 Strategies to Foster Creativity in Engineering Education

Researchers have explored a number of strategies to develop creativity in engineering education. For example, Baillie and Walker [26] pointed out that providing free learning exploration and both extrinsic and intrinsic motivations for students are good ways to develop engineering students' creativity. Zampetakis et al. [27] used mind mapping to help engineering students reduce time and foster creativity for task completion. Millet et al. [28] reviewed the inventive design process in R&D departments; their findings indicated that providing more engineering practices in the engineering curriculum would benefit the development of students' creativity.

Felder [29] introduced exercises into classwork that could develop creativity and problem-solving skills among engineering students, including Alex F. Osborn's Checklist for New Ideas [30], attribute listing, morphological analysis, random simulation, and brainstorming. Felder [29] also suggested that:

> "*In every course, some open-ended and underdefined problems should be assigned, and more information than is needed should be provided for problems with unique solutions. Problems should also be assigned that call for the generation of possible alternative solutions, and when the solutions are evaluated, credit should be given for four traits of creative thinking discussed in the literature: fluency (number of solutions generated), flexibility (variety of approaches adopted), originality*, [p. 121] *and elaboration* [31, p. 44].

Strategies to encourage creativity in engineering education have also included curriculum reform. Page and Murthy [32] used a multi-level course approach to emulate actual engineering companies' environments and real-world client needs that students may be confronted with in the future, thus fostering students' creativity from the second year through the fourth year in an undergraduate program. Chen et al. [33] developed three new courses to enhance students' problem-solving skills; the improvement of students' creativity was evident in the study's outcomes. Moreover, Zhou [34] found that constructivist instructional methods, such as problem- or project-based learning, were suitable environments for embedding the teaching of creativity in engineering education. Lastly, in another study, Zhou and his colleagues found that multiple factors, including common goals, group discussion, regular meetings, and peer support, might promote group creativity [35].

3. Methodology

3.1 Participants

The study presented in this paper was part of a faculty development research project on how to incorporate creativity into instructors' teaching. The project was conducted in a college of engineering at a mid-west AAU, land-grant, R1 university in the United States. Ten engineering faculty members who were in their early careers applied for the project and voluntarily participated in a series of research studies regarding their expectations, perceptions, and experience before, during, and after the training.

The ten participants included eight males (P1, P2, P4, P6–P10) and two females (P3 & P5). Nine of them were assistant professors with less than five years of teaching experience, while one was an associate professor with more than five years of teaching experience. They shared a general background in bioengineering, and their primary appointment was in the same department, yet each had unique research focuses, including food science, biomedical engineering, natural resources, radiology, etc.

3.2 Data Collection

We used a structured interview as our data collection method. Interviews are effective research methods to understand how participants perceive a concept, a method, a process, a problem, or a phenomenon. Similar research studies that used interviews in engineering education were like the one conducted by Righter et al. [36]

Our interviews consisted of two phases, with all ten participants interviewed in each phase.

The interview questions were pre-determined. Researchers asked questions one by one during the interview. In Phase 1, two researchers interviewed the participants, focusing on why participants chose a teaching career, how they learned to teach, what they liked about teaching, and how they perceived their students' strengths and weaknesses in learning. Sample questions included, "How do you like to teach?" "Why did you choose a career in teaching and research?" "How did you learn to teach?" and "What do you think your students' strengths and weaknesses are?" etc. The purpose of this set of interviews was to help us identify the faculty's current beliefs and approaches that would predispose them to incorporate creativity and/or might pose obstacles to their willingness to integrate creativity.

In Phase 2, two different researchers conducted a second set of interviews, focusing on how participants understood creativity, which class sessions they deemed as the best fit to integrate creativity into their teaching, how they perceived the relationship between creativity and engineering, how they perceived their and their students' creativity, and what concerned them about integrating creativity into the classroom. Sample questions included, "What is your definition of creativity?" "How much do they know about the creativity in engineering?" "How creative do you think you are? How creative do you think your students are?" "Have you ever taught creativity in your classroom? Can you provide an example?" "What do you see as being the effect of teaching creativity?" etc.

The data collection took place in fall 2019 and fall 2020, with five participants for both phases each year. The interviews in fall 2019 were face-to-face, while those in fall 2020 were conducted online due to the COVID-19 pandemic. The length of the interviews ranged from 30 to 60 minutes. All interviews were audio-recorded for data analysis purposes. Participants' consent was obtained.

3.3 Data Analysis

3.3.1 Data Preparation

We transcribed the interview recordings to text using an artificial intelligence-supported transcribing tool [37]. After the auto transcription, a manual check was conducted to ensure the maximum quality of the transcription.

3.3.2 Data Analysis

The data analysis process included three steps. Firstly, we read through the transcription for two rounds. During the first round, we aimed to have an overall understanding of the participants' views. During the second round, we focused on identifying major similarities and differences among interviewees' views. Throughout the reading process, memos were used to record our understanding, thoughts, or questions regarding the content. Interview notes taken by the interviewers were also used to assist our reading and cross-check interviewees' viewpoints.

Secondly, we conducted a thematic analysis on the transcription content using NVivo 13 [38]. We used interview questions to lead the analysis. We then inferred specific codes based on the transcription content within the scope of each leading question and added corresponding text into different codes as quoted evidence. Similar codes were grouped as a theme with a name.

In addition, we counted the frequency of each code using the number of interviewees who were coded into a code (instead of using the number of pieces of quoted evidence that were coded into a code). For instance, one interviewee indicated that he loved teaching and provided two examples to illustrate how he loved teaching, but we only counted that as one for the frequency of the code "Enjoy teaching" instead of two.

Finally, we reviewed all transcription, themes, and codes to ensure that we did not miss anything.

3.3.3 Code Development

We coded the interview transcription following the interview questions. Under each question, codes were inferred based on the content of participants' answers.

Firstly, we selected nine leading questions from the interview protocol as our guidance for coding. These questions were clustered into two categories: teaching philosophies and perceptions of creativity. Table 1 shows the categories, code-leading questions, and the corresponding research questions (RQs) that the code-leading questions tried to answer.

Secondly, under each code-leading question, we inferred codes based on what participants shared with us. Contents that shared same or similar meanings were clustered together, and a code name was assigned based on the gist of the cluster. For example, under the leading question "How do you define creativity", many participants mentioned things being "new", "novel", or "that has never existed." Therefore, a code "Novelty" was assigned to these contents. The minimum recording unit was a sentence. Additionally, similar codes were grouped as a theme with a given name. For instance, codes "Help students" and "Interact with students" were grouped as a theme named "Enjoy teaching."

Details about code-leading questions, themes,

Table 1. Categories, code-leading questions, and the corresponding RQs

Categories	Code-leading Questions	RQ
Teaching philosophies	Why did you choose an academic career?	1
	How did you learn to teach?	1
	How did you like to teach?	1
	What are your students' strengths and weaknesses in learning?	1
Perceptions of creativity	How do you define creativity?	2
	How do you perceive your creativity and your students' creativity?	2a
	When in your course do you believe is the best fit to integrate creativity in your teaching?	2
	How do you perceive the relationship between creativity and engineering?	2b
	What are your concerns about integrating creativity in your classroom?	2

codes, and text evidence can be found in Section 4 Results.

4. Results

In this section, we present our results for data analysis. We cite several excerpts from the interview transcription. In the excerpts, we used italic words in the brackets for clarification purposes, for example, "*It was the teachers who made it [learning] all interesting*". In addition, any ". . ." (ellipsis) in the excerpts indicates an omission of or a break in the original transcription.

4.1 Stage 1 Results

To understand participants' teaching experiences and philosophies, we asked them a series of questions regarding why they chose a career that involves teaching, how they learned to teach, their favorite things about teaching, and their perceptions of their students' strengths and weaknesses in learning.

Overall, participants chose a career that involves teaching because they like teaching and sharing knowledge. They learned teaching skills from their previous teachers, current colleagues, or workshops/training camps that they attended. They liked interacting with students, preferred giving collaborative tasks to students, and enjoyed the moment when students demonstrated understanding.

4.1.1 Why They Chose an Academic Career

Participants chose to be faculty members at a university for various reasons. Enjoying teaching was the primary reason for becoming a faculty member because teaching allowed them to interact with and help students. For example, P2 was proud of his teaching style, "*The way that I taught was different than the way that a lot of physicists taught*." P4 said, "*I found [teaching] pretty interesting and, especially for something that I'm working on now, it's pretty new and pretty exciting*." P5 enjoyed teaching for "*interaction with students in class and after class*." P10 liked teaching because "*I like helping the students learn*." More specifically, some participants fell in love with teaching because of previous teaching experience. For example, "*It wasn't until I got into grad school and served as a TA, started to mentor undergrads in the laboratory, that I really thought this [i.e., teaching] could be something that like I really enjoy* (P6)." Some others, on the other hand, loved teaching because of being influenced by their teachers:

> "*It was inspired by particularly my teachers in high school. How easily they would introduce concepts. You know, when we were in high school, we had no access to technology; we [even] wanted electricity. So it was during daytime that we learned before the sunset. It was the teachers who made it [learning] all interesting, you know, so that's how I got interested in what they always do*" (P1).

Participants chose to teach also because they "*can learn something from teaching, and that can benefit my research* (P4)" and teaching and research "*could go both ways* (P7)." Furthermore, transferring "*what I do in my research to my students* (P3)" was also an important reason that some participants chose to teach.

In addition, one participant mentioned networking, "*You could have multiple people help you with your research . . . Soon, they go out and build your network* (P1)." Another one indicated that a faculty job allowed him to do research, "*I like research. That's the reason I'm in this job. It comes with teaching* (P9)."

4.1.2 How They Learned to Teach

Participants learned to teach through different channels or methods. Most participants (8/10) learned from their teachers, professors, advisors, or colleagues. For example, P4 learned how to teach from his post-doctoral advisor:

> "*My post-doc advisor . . . is a very famous person in the field, a pioneer in that field . . . for people at his academic level, they don't [need to] teach, but he still teaches, especially in undergraduate classes. He prepared lectures very well . . . I attended his classes. During the*

class, he would ask a lot of questions and used group discussions, and, in particular, group projects, because in the biomedical research field, there are a lot of collaborations between engineering and biomedicine, for engineers, doctors, and clinical physicians. So, [through] group discussion and group projects, students can learn how to collaborate with people in a different field or a different research area. I think that's something really impressive."

Similarly, P5 shared how she learned to teach from senior faculty colleagues in her department:

> "*I talked to Dr. A [the identities were removed for confidentiality, and hereinafter] a lot. You know, he gave me a lot of advice. And [I talked to] Dr. B, and other senior faculties, including Dr. C and so on. I even went to audit some of their lectures when I came [to work in this university]. You know, different professors had different teaching styles, but they all provided inputs to help me learn how to teach.*"

Additionally, P8 commented, "*I learned from teachers, like watching good teachers, in terms of their pacing, their techniques, and really, their ability to grip attention of students.*" When their teachers' teaching styles touched them, participants would "*use teaching styles as models* (P4)" and do "*exactly the same format that he [the teacher] taught me* (P1)."

Other methods included attending faculty development (FD) workshops (P5 and P9), watching videos in which people teach (P7), or learning from other sources (P6). P5 attended an orientation for new teachers, "*It was several years ago. We sat at a table as a group. There was some discussion about how to teach and how to develop course materials. We had discussion about teaching, shared experience, and [exchanged] what we liked most about teaching.*"

Despite their attendance, however, not all participants were satisfied with those FD programs. P2 was straightforward about the quality of one FD program that he attended:

> "*At D University [the university from which P2 earned his Ph.D.], before you start teaching for the first time, they [the university new teacher training program] have a week-long class in quotes, "How to teach," that I took nothing from. In fact, a lot of things that they taught, I really kind of pedagogically disagree with. They were teaching things that might work in a middle school class, things like what you are NOT [P2 stressed this word] to do. When your students come in, you have an activity on the board that they [the university new teacher training program] literally called Sponge Activity to soak up time in your class . . . and you're essentially given the workbook, list of activities that you need to get through for each day. And it was . . . you couldn't really deviate from that material much. It was a very rigid part of the curriculum. I didn't like that very much and I thought: what a huge waste of time for an incredibly expensive school!*"

Alternatively, many of them learned from personal experience or practice. Half of the participants learned from trial and error (P2, P7, P8, P9, and P10). For example, P2 continued:

> "*But, I did in [my] master's [study] end up getting to teach the Honors Physics Lab. And that was much more open ended. The students had a project for the semester, and you kind of coach them through that. I really worked hard to make that a good class for them. I won a teaching award for that, actually. That was kind of fun.*"

P9 said, "*I never get the training. I was never really seriously offered the training. And I did not have time to train myself. So I learned this, I guess, with experience.*" Two participants learned through personal reflection. For instance, P5 would ask herself questions such as "*If I were the professor of this class, which way would I like to teach?*"

4.1.3 How They Liked to Teach

Participants used various methods to teach. We created a word cloud to present these methods (see Fig. 1).

Due to the diversity of methods mentioned by participants, we provide evidence for some primary methods here. Many participants liked to interact with students in class. Some of them would start the lecture by "*having a casual discussion [with students]* (P1)." Some would use "*small group discussion* (P4)" and "*encourage them [students] to ask questions* (P9)." Some used group discussion in online courses as well, as P8 described his practice, "*This semester, I'm teaching online all, you know, 100% online. So, I've been using the breakout discussion groups, at least once every class, sometimes twice. Ideally, twice for a 75-minute class.*" Some would "*ask questions to students and have them answer voluntarily* (P5)" and "*particularly pay attention to students' responses and gestures* (P9)." Even if teaching in a big hall, some participants still loved to have "*communication and discussion with the class* (P5)."

Participants used various traditional teaching methods in classes. Lectures or presentations were used by more than half of them (6/10). PowerPoint slides were the primary tool that participants (P2, P5, P7, P8, & P10) used to give lectures. Sometimes they might use "*the whiteboard or blackboard* (P2 & P5)" instead. Some of them would give students individual homework "*if somebody's personal interests do not align with others or do not have any overlap* (P8)." They required their students to "*have your own version of your homework* (P5)" and "*think about by themselves independently* (P9)." as supplemented by P9:

> "*It's not directly something which I covered in [classes] because they will not find the answer by going to lecture notes, or when I tell them to go and do Google search, they will not find the answer. Because of this, they need to*

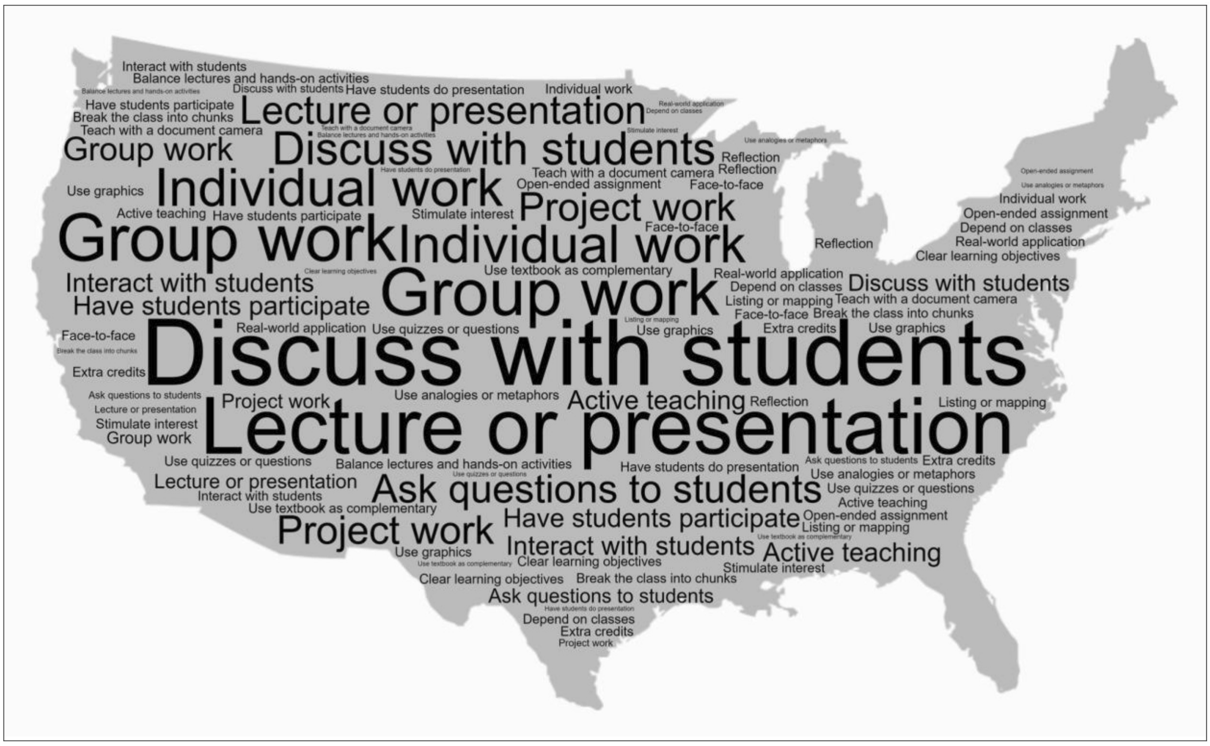

Fig. 1. A word cloud that demonstrates the frequency of instructional methods used by participants in their classrooms (larger fonts indicate more frequent use)

work on it and figure out the answer by themselves. A few students came to me and told me that my homework was challenging, but they liked it."

Some participants also adopted active learning methods. Group work and project-based assignments were their choices. For example, participants would have students do "*group discussion* (P4)" or "*brainstorming* (P5)." Others would have students "*meet as a group* (P7)" and "*work on problems in groups* (P8 & P10)." P10 introduced how he delivered his project-based courses in more detail:

"*Right now, I'm teaching two design classes: an introductory design class, and a capstone class. In both classes, I have projects. And in fact, the capstone class is . . . all of the grading is really based upon projects. I have three projects for students: an individual project, a project in a group of two [students], and a large project in a group of four [students]. That's the base of the work. So, in classes, I'll go over some additional concepts that maybe we didn't cover in the introductory design class and also talk about the projects themselves and how they [students] might approach each of these projects.*"

4.1.4 Students' Strengths and Weaknesses in Learning

Participants discussed their students' strengths and weaknesses in learning. We summarized their points in Table 2.

In participants' opinions, their students are "*very smart* (P4 and P5)," and "*have good fundamentals* (P6, P7, and P10)." They are "*willing to learn and to interact with professors* (P5)." They "*like challenges* (P5)" and "*are open to new things* (P8)."

As for weaknesses, P4 indicated that his students had "*unbalanced background knowledge*." Participants complained that their students were "*used to fixed answers* (P6, P7, and P10)" and "*impatient* (P8)," "*pay too much attention to the grade* (P9)," and lacked "*the ability to learn new ways to learn* (P7)" and "*to define and approach problems* (P6)."

4.2 Stage 2 Results

For participants, creativity meant developing something new and beneficial to society, and there

Table 2. Students' strengths and weaknesses identified by ten participants

Strengths	Frequency	Weaknesses	Frequency
Talented	5	Capability	3
Open-minded	5	Fixed mindset	3
Dedicated	2	Learning preferences	2
Like challenges	1	Personality	2
Morality	1	Various disciplinary backgrounds	1

was a strong relationship between creativity and engineering. Most of them believed that they were creative and that their students were creative but in different ways. Their concerns about integrating creativity into their teaching included that it would be time-consuming, that they lacked the knowledge to do so, that they lacked the necessary soft skills (e.g., communication), and that assessing creativity would be difficult.

4.2.1 Participants' Definition of Creativity

Fig. 2 indicates participants' definition of creativity. Overall, all participants believed that creativity meant being new or novel. Specifically, students should "*think out of the box* (P1)," "*have new ideas, approaches, and ways to do different things* (P5)," and "*think about things in a non-traditional way* (P6)." P1 illustrated his point with an example of a startup company, "*Once I visited a small startup in San Francisco. They did similar work that I teach in classes. It was just three people who started in an abandoned warehouse. It was a simple idea, but it worked. A few years later, that startup was bought by Monsanto for a billion dollars*." P9, instead, used kitchens and food to explain creativity, "*You can go to kitchens and bring different types of food together. We don't invent anything, but we may get them [food] by putting a Thai kitchen and an Italian kitchen together. They both exist, but you figure out what comes out when they [are] put together*."

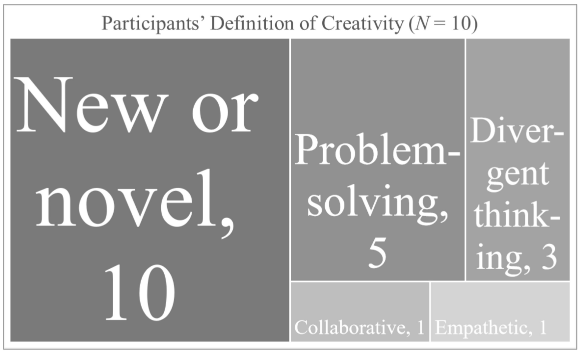

Fig. 2. A treemap of participants' definitions of creativity

Problem-solving is another essential aspect of participants' creativity definitions. According to them, creativity meant to "*use resources and tools available to you to address problems* (P8)" through "*integrating knowledge* (P6)." Meanwhile, the solutions should be "*applicable to different places* (P1)" and "*have a positive effect* (P9)."

Other components of creativity included divergent thinking, to "*see things and solve problems in a different way* (P6, P7, and P10)," collaboration, to "*be able to work with others* (P6)," and being empathetic, to "*express something that can give joy to someone* (P3)."

4.2.2 Participants' Perceptions of their own and Students' Creativity

Interviewees provided varying perceptions of their own and their students' creativity (see Table 3).

Firstly, seven out of ten (7/10) participants thought that they were creative. For instance, P2 was very confident about himself, "*I'm exactly as creative as I should be . . . Am I any more creative than the average physicist? Yes!*" In addition, two participants deemed that their creativity varied depending on the topic. For example, P9 described himself as "*I'm creative in some things. For example, I can find solutions to things very quickly. But I'm not creative in artistic sense*." Only one participant (P4) rated himself as "*not a very creative person. I'm trying to learn, still in a learning process.*"

Secondly, six out of ten (6/10) participants perceived that their students were creative in different ways, acknowledging that creativity can manifest in many behaviors, actions, and scenarios. For example, P5 mentioned that "s*ome of them are creative. They can come up with a lot of ideas and can find a*

Table 3. Participants' perceptions of their own and students' creativity

Participant	Perceptions of their own creativity			Perceptions of their students' creativity		
	Not creative	**Creative**	**Creative differently**	**Not creative**	**Creative**	**Creative differently**
P1		•				•
P2		•			•	
P3		•				•
P4	•					•
P5		•				•
P6		•				•
P7			•	•		
P8		•			•	
P9			•			•
P10		•		•		
Total	1	7	2	2	2	6

way to solve a problem . . . Some are really not creative. They like structured tasks and if I ask them to think critically, they seem not able to do it fairly well." P6 shared similar perceptions, "*Some students can come up with really interesting and cool solutions. Other students still feel like . . . I need to give them the answer.*" Students' creativity might also be different upon task design. P3 explained, "*If there is an assignment that is more restricted, students might lose the chances to become creative. But if we give them a little bit relaxation, they can really surprise you with amazing results.*"

Two participants thought that their students were not creative. P7 believed that "*a lot of students' creativity is smothered by fear. They've been taught so often that they need to give the right answer, and they've been trained not to think outside the box.*" P10 pointed out that students "*like to be economical in their time that they put into schooling, just like 'Show me how to do it, and I'll do it that way' rather than wanting to put it [time] in thinking if there is a different way.*"

4.2.3 When to Integrate Creativity in Teaching?

Participants provided different scenarios or timings that they believed best fit to integrate creativity into their teaching. Some pointed out that the best time to integrate creativity was when they needed students to imagine "*how you are going to build it* (P1)," to think "*what is going to drive innovation* (P8)," to ponder "*different ways to approach a problem* (P6)," and to consider "*what is worth pursuing* (P2)."

Other participants believed that when they "*gave assignments* (P4, P10, and P6)" or "*in-class discussion* (P5)," or when they tried to "*communicate some concepts back to students* (P7)," it would be the best time to integrate creativity in teaching.

Specifically, P4 described a moment he believed good to integrate creativity:

> "*Last semester, we wanted our students [to] design some kind of pressure sensor for diabetics patients. They [diabetics patients] had a high chance to develop foot ulcer, causing some wound or foot ulcer. So, basically, the idea was that, can we design some kind of smart bandage that can measure the pressure? Also, most importantly, can we deliver some therapies to treat this foot ulcer? Some students came up really smart ideas. They could measure temperature change using temperature sensors and the [blood pressure using] pressure sensors, and they had some closed-loop control system that could deliver some drugs into the wound.*"

P7, alternatively, introduced another moment for creativity integration from the communication perspective:

> "*[In a funnel design project,] there's a lot of creativity in client interactions. Because your client may not be an engineer, may not have the same language that we speak, so, communicating those concepts back to a differently educated client requires some creativity. Doing the work to brainstorm alternatives and think outside the box in terms of how a client's problem might be resolved requires a lot of creativity, and then the presentation of the funnel design, making sure that the client understands the concepts, and there are other audiences, you know, secondary audiences and things like that. You have to pitch it, right? I mean, you have to make sure that people are interested in your design.*"

Two participants (P6 and P7) urged the department to integrate creativity early in the program curriculum. They believed that creativity should be incorporated as early as the first year of undergraduate study.

4.2.4 The Relationship Between Creativity and Engineering

As is shown in Fig. 3, more than half the participants believed that creativity was the source of many engineering solutions. P4 used Apple Watch to illustrate how creativity plays its role: "*Back to 10 years ago, diabetes patients should take their blood samples each day . . . but these days, the patients can just apply the pinch on their screen. They can continuously measure the glucose level in a minimally invasive method.*"

According to the participants, engineering was full of uncertainties, unfamiliar situations, or complex issues. For example, P1 explained:

> "*There are lots of uncertainties . . . you cannot always know what to do. In construction, [suppose] I have excavated [a land] for 10 feet, and then there's a building standing up next to it. It started raining suddenly. I'm putting the building standing next to my excavation under risk. How should I address that? I have a very short time window to either fill the hole back or do something else.*"

P7 agreed, "*The actual problems that they [students] will face in real life are far more complex than anything we can give them.*" Creativity, however, is a powerful weapon for them to deal with these challenges. For instance, P8 said, "*Creativity*

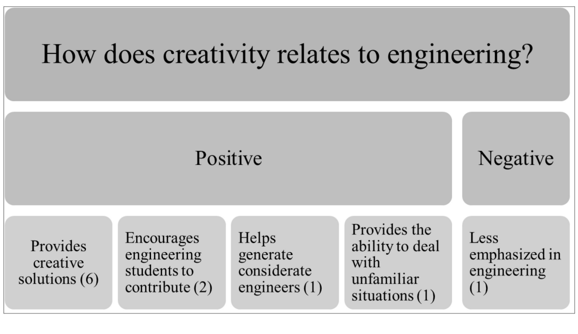

Fig. 3. Participants' identifications of the relationship between creativity and engineering (the number in the parenthesis indicates the frequency count of the relationship identified by participants).

allows engineers to remove themselves from certain sets of confines, boundaries, or limits.'' P9 held that ''*we learn so many engineering tools and methods. But if you only stick to what you are taught, then nothing will improve. So you need to go a little bit further*.''

Secondly, creativity encourages more engineering students to make contributions to the field and society. With creativity, students can ''*solve grand challenges and big problems* (P3)'' and ''*apply it to any scenario, not only classes but also any activities they are participating in, and even daily life* (P5).''

Finally, creativity helps engineers think more comprehensively, as P1 emphasized that creativity helps engineers ''*be good in creative situations where they know they can think about all the possible extreme cases*.''

4.2.5 Issues/concerns about Integrating Creativity in Classrooms

The participants had various concerns regarding integrating creativity into the classroom. They (4/10) most worried about how much time they needed ''*to incorporate creativity into their teaching* (P8).'' They commented, ''*My time is valuable, I don't know how much time it will take* (P9),'' ''*I shouldn't spend too much time and I'm in a tenure track, so I need to get publications* (P3),'' and ''*Of teaching creativity . . . the con is that it does take a lot more time* (P2).

Some of them (2/10) found that lack of knowledge could be an obstacle for them to incorporate creativity into teaching, ''*It could be done in all aspects, like problem-solving, fundamentals, but we just don't know how to do it [incorporate creativity into teaching], or we haven't invested so much of time to think about how we incorporate or how we make it come* (P3).''

In addition, participants pointed out that they needed facilities or resources to support creativity incorporation (P1), process skills (e.g., communication) to be creative (P3), and criteria or rubrics to assess the effectiveness of creativity (P2).

5. Discussion and Implications

The data analysis helped us identify several key concerns that could be addressed through appropriate faculty development opportunities, such as lack of knowledge about teaching creativity, how to incorporate it into the class, and how to evaluate it. We also identified typical engineering classroom activities where faculty members thought incorporation would be successful, including not just the typical engineering design projects, where we would expect to see a high level of creative approaches, but also generally in class discussions, in decision-making processes, in needs-finding, and in problem-solving. Lastly, we identified potential themes that describe a common view of the relationship between creativity and engineering: creativity makes space for students' contributions, creativity helps generate thoughtful and considerate engineers, and creativity provides a broader range of types of solutions to complex problems. By building upon these common themes, academic leadership and faculty involved in curricular analysis and review can more easily identify classes, and modules or elements within those classes, where creative approaches can be discussed and leveraged. They may find it more straightforward to encourage faculty members and instructors to integrate creativity in instruction since it builds on a shared understanding of the need for and importance of creativity in engineering.

5.1 Engineering Faculty Members' Teaching Philosophies

According to our results, early-career engineering faculty members learned teaching skills mainly from their previous teachers, professors, or advisors. If they found any of their teachers' teaching methods or skills compelling, they might take them as models and apply them in their teaching. Meanwhile, they also learned how to teach from their current colleagues, especially from senior professors who had many years of teaching experience in higher education. These results aligned with previous researchers' findings that most faculty members developed their teaching skills through watching how others taught [39]. Additionally, some participants in this study attended orientations, workshops, or training campaigns prepared for early-career faculty members and incorporated their thinking and reflection into the teaching practice. This strategy echoed previous researchers' point that ''smaller and more focused training'' was helpful to faculty members' teaching development [40, p. 5]. While some workshops as a whole might not be seen as particularly useful, some strategies learned might be effective in saving the junior professors time and energy to think about implementing quality teaching during the early stages of their academic careers.

Our participants enjoyed their teaching. They loved the interaction with students. Sound faculty-student interaction benefits students' motivation [41] and learning outcomes [42]. They appreciated the moment when their students understood the course material or found their teaching helpful. Participants believed that teaching benefits research and vice versa, though this belief as a research topic might still be controversial [43]. Participants conveyed the knowledge that they gained from research to their students while pursuing their research interests.

Participants in our study had a preliminary awareness of implementing active learning in their classes. For example, more than half of them indicated that they would "*actively engage*" students in "*group discussion*" and have students "*collaborate*" on "*real-world problem*." Previous studies have proved the effectiveness of active learning [44] and indicated that using active learning methods would enhance students' performance in STEM fields [45]. Our participants believed that their students were used to fixed answers or mindsets, so they would like to adopt active learning methods to make students take more initiative to learn and think.

Unlike faculty members in a college of education who may be immersed in education theories, frameworks, or models, many engineering faculty members explore and develop teaching skills from teaching practice. Previous research showed that engineering faculty looked for methods that have been proven to work (evidence-based teaching practices) rather than trying to explore the breadth of educational theories and concepts [44]. If a teaching method yields positive student reactions or learning outcomes, they will use it; otherwise, they may turn to other methods. They learn how to teach in various ways, but they are *pragmatic* in selecting a teaching method according to its effectiveness.

Considering the sheer contrast between participants who learned teaching from their teachers and those who learned from workshops, we see a necessity to provide more faculty development projects for early-career engineering faculty members, including workshops, mentorship, and a learning community [46]. Similar suggestions were raised by previous researchers as early as 2005 [47]. We proposed the suggestion because instructors' teaching philosophies and selection of methods in teaching practices could impact students' creativity [48]. Some of our participants were used to giving lectures in class, while others preferred using open discussion, assigning collaborative projects, and appreciating multiple solutions. Project-based learning nurtures students' creativity [49] through ways such as encouraging them to think outside the box or take risks (not afraid of making mistakes), and meanwhile, previous researchers suggested instructors should not always lecture if the teacher wants to develop students' creativity [50].

A good example is that students' critical thinking ability may get enhanced when their teachers challenge them with tough questions [51]. Critical thinking ability and creativity are considered as intertwined [52], and the former can predict the latter [53–55]. These are things that engineering instructors should be aware of. We regret, however, that, after more than 15 years, in some cases, many engineering faculty members still rely on their own abilities to develop teaching skills. We recommend more hands-on exercises and project-based assignments instead of tedious lecturing so that early-career faculty members will gain more practice opportunities and first-hand experience from these workshops. In addition, online or virtual format workshops and communities with game-based elements might be considered so that the number of beneficiaries can scale up and they might be more motivated.

5.2 Engineering Faculty Members' Understanding of Creativity and its Relationship with Engineering

Overall, participants in our study believed that creativity is the power source that moves the field of engineering forward and empowers engineering students by encouraging them to think outside the box, complete tasks in new ways, propose or make things that do not exist, and provide new, effective, and meaningful solutions to problems. These definitions virtually repeated what previous researchers had discussed, such as El-Murad and West's work [2] and Runco and Jaeger's [3]. Creativity means, for our participants, a cognitive ability that may improve a product (e.g., enhance the quality, or scale up the effect) or the process of making the product (e.g., regulate the procedures, or increase the efficiency), and may improve students' skillfulness, lower the difficulty of the work, and optimize safety measures. This understanding partially parallels Walia's definition that creativity is a cognitive ability that deals with or challenges a disequilibrium found in the social environment and finally leads to a physical, mental, or emotional creation [56].

In addition, according to our participants, creativity involves goals such as "*transfer to application*" and "*bring benefits to society*." Indeed, participants continually emphasized the need for the application to real-world issues and stated that creativity results should benefit society. During the creation process, participants thought that students should always consider whether a process, an approach, or a procedure would lead to the goals above and may need to figure out new ways to achieve these goals. In this sense, the participants envisioned creativity as a thinking process and a dynamic mental status during task completion. This finding aligns with other researchers' arguments (e.g., [57]).

Our participants' understanding of creativity seems to mix Big-C creativity and Little-C creativity [58]. On the one hand, participants expected that their students would start to be creative in small things (Little C) [59], such as completing assignments or coming up with solutions to problems with some creative ideas. On the other hand, participants looked forward to when their students could make more immense contributions or significant changes to their field or the industry (Big C) [60].

Most of our participants believed that they were creative. These ratings indicated that they had higher confidence or expectation in creatively delivering teaching to students. Meanwhile, more than half of the participants rated their students as creative in some aspects. Their ratings revealed that they observed how their students were creative in various respects. These observations would inform them where to further foster students' creativity using appropriate teaching methods.

Our participants' perceptions of who is or is not creative can be related to the concept of self-efficacy [61, 62]. Psychologist Albert Bandura's [63] theory of self-efficacy proposes that people's beliefs in their capability to achieve a task affect their actual ability to achieve that task – if they have the needed skills. Studies show that people who rate their self-efficacy high for a particular task will be better motivated and perform better than people with more ability who rate their self-efficacy lower [63]. Creativity experts such as Sir Ken Robinson [64] argued that all humans are born with "huge creative capacities" (p. 4) but that many students are conditioned to believe that people are born either creative or not creative. They think they inherently lack creativity, but exploring self-efficacy may encourage them to discover their innate creative potential [64].

Finally, creativity means not merely being new but also influencing parameters, criteria, and constraints of the problems being solved. A creative engineer must be able to consider as many cases (even extreme cases) as possible to ensure that the new idea works well.

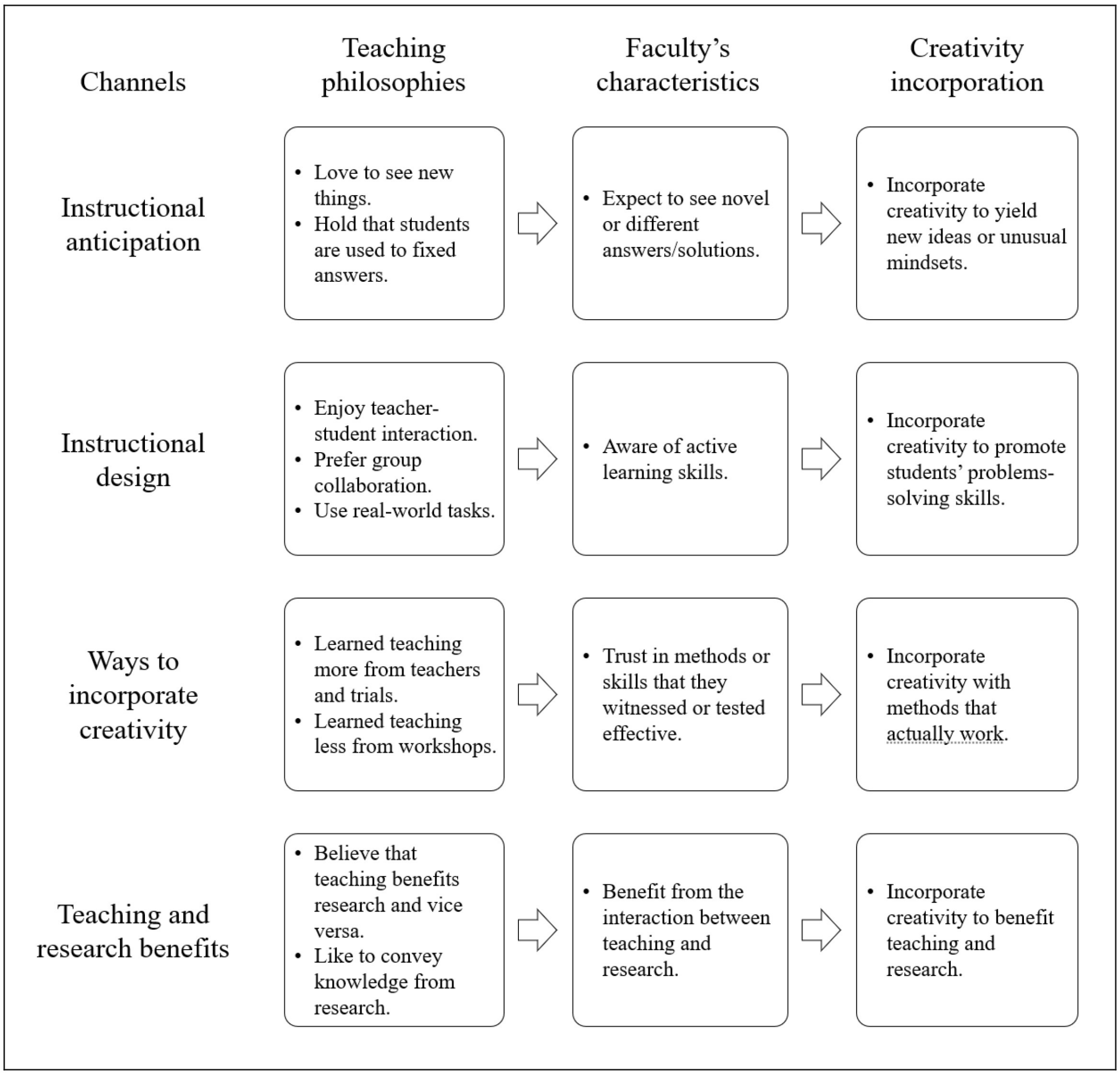

Fig. 4. Four channels of how participants' teaching philosophies may affect their creativity incorporation into the classroom: instructional anticipation, instructional design, ways to incorporate creativity, and teaching & research benefits.

5.3 How Teaching Philosophies Affect Engineering Faculty Members' Understanding of Incorporating Creativity in Engineering Classes

From the results, we found that engineering faculty members' teaching philosophies did affect their understanding of incorporating creativity in engineering classes. The influence took place through the following channels (see Fig. 4).

First, instructional anticipation. Our findings indicated that (1) engineering faculty members anticipated seeing new ideas or solutions in students' work, and (2) some engineering faculty members believed their students were used to fixed answers. When they gave students tasks or assignments, their expectation for novel and different answers or solutions made it an excellent time to incorporate creativity in teaching, which might encourage (or force) students to think outside the box and foster creativity during their completion of the tasks.

Second, instructional design. According to our findings, engineering faculty members were aware that instructional design choices might impact students' creativity [65]. For example, some of our participants claimed that assignments with fewer constraints or restrictions could lead to students naturally being more creative in their solutions or problem-solving methods, without sacrificing academic rigor. In addition, they recognized the importance of active learning, teacher-student interaction, and group collaboration. Therefore, they would use these teaching skills or strategies to promote students' creativity. For instance, Asogwa and his colleagues' practice of using YouTube problems (written by previous students, published to YouTube with concept-introducing videos, and assigned to current students) to promote students' performance in problem-solving [66] was a very good, easy-to-use example of using creative instructional methods to foster students' creativity. Another way to foster students' creativity was to provide them with real-world data as other researchers have done (e.g., [67]) or to challenge them for more creative problem-solving skills [68].

Third, being pragmatic. Our participants learned teaching more from watching and imitating their previous teachers and from trial and error and less from faculty development workshops. As a result, they place more trust in teaching methods or skills that they had witnessed or tested that were found to be effective. Although active learning theory is well-supported in engineering education [69], engineering faculty members' uptake may still be reluctant if their understanding of the pedagogical underpinnings and concrete methods is different from their own educational experience. Instead of using proven methods, they would use whatever methods work well in their classes to incorporate creativity into their teaching.

Finally, mutual benefits between teaching and research. Some of our participants believed that teaching would benefit their research because they would be inspired through the interaction and collaboration with students, and vice versa, because they could convey the latest knowledge they acquired from research to their students. This belief may encourage early-career engineering faculty members to incorporate creativity more into their teaching.

6. Limitations and Future Work

Colleges of engineering cover dozens of degree programs and disciplines. In our study, we only interviewed ten faculty members from one department. Nine of them had less than five years of teaching experience, while one had been teaching for more than five years. They all share a bioengineering background but differ on specific research foci. Future studies may include more participants from different engineering backgrounds and faculty members from other departments for comparison purposes. In addition, cross-university studies, if possible, would allow for differences in the academic culture of creativity and connections of creativity to the specific discipline.

Five participants in our study are from various countries located within the Asian continent, and the other five are from the United States. During interviews, two participants stated their country of origin, elaborated on a particular educational experience before arriving in the U.S., and described shifts in their own learning foci and subsequent teaching philosophy as they began to teach in America. During post-interview discussions, the research team began to postulate how participants' cultural experiences and familiarity with education outside the United States had impacted how they conceptualized teaching philosophies and the role of creativity while working at a higher education institution in the U.S.; as well as how different cultural models of education impacted the participant's understanding of creativity and its relationship to engineering. To be clear, we point to these findings to contribute to the evolving understanding of creativity research in engineering and not to propose cross-cultural experiences as an obstacle. The considerations in this paragraph have not been extensively explored in the field of engineering but have been investigated in the fields of education [70] and psychology [71].

Another limitation of this article is that we exclusively focused on the engineering faculty's voice. Additional research needs to be conducted to investigate and juxtapose students' perceptions about creativity and the impact of faculty members' use of techniques on students' performance and perceptions.

7. Conclusion

The world calls for more engineers who offer creative ideas, critical thinking, and strong problem-solving skills. It was, therefore, surprising to see in the previous literature that undergraduate students do not appear to consider creativity an essential part of engineering; moreover, the recognition that creativity typically is not discussed, developed, or integrated explicitly into engineering coursework, outside of engineering design classes, is concerning. Integrating creativity into the engineering classroom purposefully, both implicitly and explicitly, could be a powerful tool in the engineering skills toolbox for our students. However, to do this, faculty members must themselves have a level of comfort with creativity – and how it can be incorporated into their classes – in order to integrate creativity into the engineering curriculum intentionally.

In this study, we interviewed ten early-career engineering faculty members regarding their educational philosophies, teaching strategies, understanding of creativity, and perceptions of the correlation between creativity and engineering. We found that these instructors carried teaching philosophies that showed nuance and different elements informed by active learning pedagogies and their own ways of being taught. It is not surprising that instructors' teaching philosophies inform their views on creativity in engineering and issues and concerns about how to incorporate creativity into their classrooms.

As the participants in this study demonstrated, creativity is not a monolith. There are many routes to incorporating creativity into the engineering curriculum, and faculty members' own perceptions, ideas, and understanding of creativity can lead to new and exciting teaching practices that could bolster engineering students' creativity. This study presents a unique viewpoint – a faculty-led viewpoint – of how we can combat the downward slide of creativity in engineering and suggest paths forward or opportunities to build on faculty members' existing perceptions of creativity within engineering.

It is a critical mission for engineering faculty members to help engineering students become creative, innovative engineers. Can creativity be taught? We believe that creativity *can* be taught, as long as faculty have a sound understanding of creativity, engineering, and the appropriate instructional design and implementation of creativity in engineering education. To support faculty's instructional efforts, we first need to know where faculty members stand and where they are coming from so that we can meet them where they are and help them find where to go next. This study contributed the first step into a series of studies and exploration of different interventions.

Acknowledgments – The study presented in this article was supported by the National Science Foundation (NSF) with grant number 1836857.

References

1. R. J. Sternberg and T. I. Lubart, The Concept of Creativity: Prospects and Paradigms, in *Handbook of Creativity*, Cambridge University Press, Cambridge, UK, pp. 3–15, 1999.
2. J. El-Murad and D. C. West, The Definition and Measurement of Creativity: What Do We Know?, *J. Advert. Res.*, **44**(2), pp. 188–201, 2004.
3. M. A. Runco and G. J. Jaeger, The Standard Definition of Creativity, *Creat. Res. J.*, **24**(1), pp. 92–96, 2012.
4. M. A. Runco, Personal creativity: Definition and developmental issues, *New Dir. Child Adolesc. Dev.*, **1996**(72), pp. 3–30, 1996.
5. D. Y. Ford and J. J. Harris, The Elusive Definition of Creativity, *J. Creat. Behav.*, **26**(3), pp. 186–198, 1992.
6. Berg Holger, Fostering creativity – a holistic framework for teaching creativity, *Dev. Learn. Organ. Int. J.*, **26**(6), pp. 5–8, 2012.
7. A. S. Blicblau and J. M. Steiner, Fostering Creativity Through Engineering Projects, *Eur. J. Eng. Educ.*, **23**(1), pp. 55–65, 1998.
8. D. Grasso and M. B. Burkins, Beyond Technology: The Holistic Advantage, in D. Grasso and M. B. Burkins (eds), *Holistic engineering education: beyond technology*, Springer, New York, NY, USA, pp. 1–10, 2010.
9. D. H. Cropley, Creativity in Engineering, in G. E. Corazza and S. Agnoli (eds), *Multidisciplinary Contributions to the Science of Creative Thinking*, Springer Singapore, Singapore, pp. 155–173, 2016.
10. W. B. Stouffer, J. S. Russell, and M. G. Oliva, Making The Strange Familiar: Creativity and the Future of Engineering Education, *Proceedings of ASEE 2004 Annual Conference*, Salt Lake City, UT, USA, 2004.
11. D. H. Cropley, Promoting creativity and innovation in engineering education, *Psychol. Aesthet. Creat. Arts*, **9**(2), pp. 161–171, 2015.
12. D. H. Cropley and A. J. Cropley, Engineering Creativity: A Systems Concept of Functional Creativity, in J. C. Kaufman and J. Baer (eds), *Creativity across Domains: Faces of the Muse*, vol. **1**, pp. 169–185, 2005.
13. B. Ibrahim, Exploring the relationships among creativity, engineering knowledge, and design team interaction on senior engineering design projects, phd, Colorado State University, 2012. Accessed: Aug. 17, 2020.
14. Z. Liu and D. J. Schoènwetter, Teaching Creativity in Engineering, *Int. J. Eng. Educ.*, **20**(5), pp. 801–808, 2004.

15. J. Lin, Creativity Engineering for Continuous and Discontinuous Innovation, *2006 Technology Management for the Global Future – PICMET 2006 Conference*, Istanbul, Turkey, pp. 767–777, Jul. 2006.
16. S. R. Daly, E. A. Mosyjowski and C. M. Seifert, Teaching Creativity in Engineering Courses: Teaching Creativity in Engineering Courses, *J. Eng. Educ.*, **103**(3), pp. 417–449, 2014.
17. K. Kazerounian and S. Foley, Barriers to Creativity in Engineering Education: A Study of Instructors and Students Perceptions, *J. Mech. Des.*, **129**(7), pp. 761–768, 2007.
18. C. Lawrence, V. A. Foster and C. L. Tieso, Creating Creative Clinicians: Incorporating Creativity Into Counselor Education, *J. Creat. Ment. Health*, **10**(2), pp. 166–180, 2015.
19. K. S. Bull, D. Montgomery, and L. Baloche, Teaching Creativity at the College Level: A Synthesis of Curricular Components Perceived as Important by Instructors, *Creat. Res. J.*, **8**(1), pp. 83–89, 1995.
20. G. Thompson and M. Lordan, A review of creativity principles applied to engineering design, *Proc. Inst. Mech. Eng. Part E J. Process Mech. Eng.*, **213**(1), pp. 17–31, 1999.
21. L. L. Gordy and A. Peary, Bringing Creativity Into the Classroom: Using Sociology to Write First-Person Fiction, *Teach. Sociol.*, **33**(4), pp. 396–402, 2005.
22. C. Charyton and G. E. Snelbecker, General, Artistic and Scientific Creativity Attributes of Engineering and Music Students, *Creat. Res. J.*, **19**(2–3), pp. 213–225, 2007.
23. F. M. Pfeiffer, R. E. Bauer, S. Borgelt, S. Burgoyne, S. Grant, H. K. Hunt, J. J. Pardoe and D. C. Schmidt, When Theater Comes to Engineering Design: Oh How Creative They Can Be, *J. Biomech. Eng.*, **139**(7), pp. 1–4, 2017.
24. F. M. Pfeiffer, S. Burgoyne, H. K. Hunt and J. Strobel, Balancing Academic Rigor and Creative Thinking: A Transformational Approach to Teaching Senior Design, *J. Biomech. Eng.*, **140**(8), pp. 1–3, 2018.
25. T. Davies, Incorporating creativity into teachers practice and self-concept of professional identity, *J. Educ. Change*, **14**(1), pp. 51–71, 2013.
26. C. Baillie and P. Walker, Fostering Creative Thinking in Student Engineers, *Eur. J. Eng. Educ.*, **23**(1), pp. 35–44, 1998.
27. L. A. Zampetakis, L. Tsironis and V. Moustakis, Creativity development in engineering education: the case of mind mapping, *J. Manag. Dev.*, **26**(4), pp. 370–380, 2007.
28. C. Millet, D. Oget and D. Cavallucci, Open the 'black box' creativity and innovation: a study of activities in R&D departments. Some prospects for engineering education, *Eur. J. Eng. Educ.*, **42**(6), pp. 1000–1024, 2017.
29. R. M. Felder, Creativity in Engineering Education, *Chem. Eng. Educ.*, **22**(3), pp. 120–125, 1988.
30. J. E. Arnold, Useful Creative Techniques, in S. J. Parnes and H. F. Harding (eds), *A Source Book for Creative Thinking*, Charles Scribner's Sons, New York, 1962.
31. K. Goff, *Everyday creativity: An easy-to-read guide*, 3rd ed, Little Ox Books, Mannford, OK, USA, 2005.
32. N. W. Page and D. N. P. Murthy, A Programme to Integrate Engineering, Creativity and Management in Undergraduate Teaching, *Eur. J. Eng. Educ.*, **15**(4), pp. 369–381, 1990.
33. C. Chen, B. C. Jiang and K. Hsu, An empirical study of industrial engineering and management curriculum reform in fostering students' creativity, *Eur. J. Eng. Educ.*, **30**(2), pp. 191–202, 2005.
34. C. Zhou, Integrating creativity training into Problem and Project-Based Learning curriculum in engineering education, *Eur. J. Eng. Educ.*, **37**(5), pp. 488–499, 2012.
35. C. Zhou, A. Kolmos and J. D. Nielsen, A problem and project-based learning (PBL) approach to motivate group creativity in engineering education, *Int. J. Eng. Educ.*, **28**(1), pp. 3–16, 2012.
36. J. Righter, M. V. Elena and J. D. Summers, Establishing Faculty Perceptions of Undergraduate Engineering Design Team Leadership, *Int. J. Eng. Educ.*, **36**(2), pp. 814–827, 2020.
37. Otter.ai, https://otter.ai/, 2020.
38. QSR International Pty Ltd, *NVivo qualitative data analysis software*, https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home/, 2020.
39. P. Kugel, How professors develop as teachers, *Stud. High. Educ.*, **18**(3), pp. 315–328, 1993.
40. S. W. Schmidt, C. M. Tschida and E. M. Hodge, How Faculty Learn To Teach Online: What Administrators Need to Know, *Online J. Distance Learn. Adm.*, **19**(1), pp. 1–12, 2016.
41. T. L. Trolian, E. A. Jach, J. M. Hanson and E. T. Pascarella, Influencing Academic Motivation: The Effects of Student–Faculty Interaction, *J. Coll. Stud. Dev.*, **57**(7), pp. 810–826, 2016.
42. J. J. Endo and R. L. Harpel, The effect of student-faculty interaction on students' educational outcomes, *Res. High. Educ.*, **16**(2), pp. 115–138, 1982.
43. M. J. Prince, R. M. Felder and R. Brent, Does Faculty Research Improve Undergraduate Teaching? An Analysis of Existing and Potential Synergies, *J. Eng. Educ.*, **96**(4), pp. 283–294, 2007.
44. M. Prince, Does Active Learning Work? A Review of the Research, *J. Eng. Educ.*, **93**(3), pp. 223–231, 2004.
45. S. Freeman, S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt and M. P. Wenderoth, Active learning increases student performance in science, engineering, and mathematics, *Proc. Natl. Acad. Sci.*, **111**(23), pp. 8410–8415, 2014.
46. R. Brent and R. M. Felder, Helping new faculty get off to a good start, *Proceedings of ASEE 2000 Annual Conference*, St. Louis, MO, USA, pp. 1–7, Jun. 2000.
47. P. C. Wankat and F. S. Oreovicz, Teaching Prospective Engineering Faculty How to Teach, *Int. J. Eng. Educ.*, **21**(5), pp. 925–930, 2005.
48. X. Jia, W. Hu, F. Cai, H. Wang, J. Li, M. A. Runco and Y. Chen, The influence of teaching methods on creative problem finding, *Think. Ski. Creat.*, **24**, pp. 86–94, 2017.
49. T.-T. Wu and Y.-T. Wu, Applying project-based learning and SCAMPER teaching strategies in engineering education to explore the influence of creativity on cognition, personal motivation, and personality traits, *Think. Ski. Creat*, **35**, pp. 1–10, 2020.
50. G. B. Esquivel, Teacher behaviors that foster creativity, *Educ. Psychol. Rev.*, **7**(2), pp. 185–202, 1995.
51. W. Shim and K. Walczak, The Impact of Faculty Teaching Practices on the Development of Students' Critical Thinking Skills, *Int. J. Teach. Learn. High. Educ.*, **24**(1), pp. 16–30, 2012.
52. J. Y. F. Lau, *An introduction to critical thinking and creativity: think more, think better*, Wiley, Hoboken, NJ, USA, 2013.

53. B. M. Gadzella and E. Penland, Is Creativity Related to Scores on Critical Thinking?, *Psychol. Rep.*, **77**(3), pp. 817–818, 1995.
54. J. Siburian, A. D. Corebima, İbrohim and M. Saptasari, The Correlation Between Critical and Creative Thinking Skills on Cognitive Learning Results, *Eurasian J. Educ. Res.*, **19**(81), 2019.
55. A. Fatmawati, S. Zubaidah, S. Mahanal and Sutopo, Critical Thinking, Creative Thinking, and Learning Achievement: How They are Related, *J. Phys. Conf. Ser.*, **1417**(1), pp. 1–9, 2019.
56. C. Walia, A Dynamic Definition of Creativity, *Creat. Res. J.*, **31**(3), pp. 237–247, 2019.
57. R. L. DeHaan, Teaching Creativity and Inventive Problem Solving in Science, *CBE – Life Sci. Educ.*, **8**(3), pp. 172–181, 2009.
58. J. C. Kaufman and R. A. Beghetto, Exploring "mini-c": Creativity across Cultures, in R. L. DeHaan and K. M. V. Narayan (eds), *Education for Innovation: Implications for India, China and America*, Brill | Sense, Rotterdam, Netherland, pp. 165–180, 2008.
59. A. Craft, *Teaching Creativity: Philosophy and Practice*, Routledge, New York, 2000.
60. T. M. Amabile, S. G. Barsade, J. S. Mueller, and B. M. Staw, Affect and Creativity at Work, *Adm. Sci. Q.*, **50**(3), pp. 367–403, 2005.
61. D. H. Cropley, Teaching engineers to think creatively, in R. Wegerif, L. Li and J. C. Kaufman (eds), *The Routledge International Handbook of Research on Teaching Thinking*, 1st ed, Routledge, London, pp. 402–410, 2015.
62. F. M. Pfeiffer, S. Burgoyne, H. K. Hunt, J. Strobel, R. E. Bauer, J. J. Pardoe, S. P. Simkins, M. E. Vansant, J. Saboorizadeh, K. Busselle and W. Palmer, Creativity Theory and Action in Bioengineering Class, in S. Burgoyne (ed), *Creativity in Theatre*, vol **2,** Springer International Publishing, Cham, pp. 247–268, 2018.
63. A. Bandura, *Self-efficacy: The Exercise of Control*, Freeman, New York, 1997.
64. S. K. Robinson, *Out of our Minds: Learning to be creative*, John Wiley & Sons, Inc., Hoboken, NJ, USA, 2012.
65. E. R. Petty, Engineering curricula for encouraging creativity and innovation, *Eur. J. Eng. Educ.*, **8**(1), pp. 29–43, 1983.
66. U. Asogwa, T. R. Duckett, A. P. Malefyt, L. Stevens, G. Mentzer and M. W. Liberatore, Comparing Engineering Problem-Solving Ability and Problem Difficulty Between Textbook and Student-Written YouTube Problems, *Int. J. Eng. Educ.*, **37**(5), pp. 1414–1428, 2021.
67. A. W. Court, Improving Creativity in Engineering Design Education, *Eur. J. Eng. Educ.*, **23**(2), pp. 141–154, 1998.
68. J. R. Clegg and K. R. Diller, Challenge-based instruction promotes students' development of transferable frameworks and confidence for engineering problem solving, *Eur. J. Eng. Educ.*, **44**(3), pp. 398–416, 2019.
69. M. Christie and E. de Graaff, The philosophical and pedagogical underpinnings of Active Learning in Engineering Education, *Eur. J. Eng. Educ.*, **42**(1), pp. 5–16, 2017.
70. R. Lozano and A. Joanne, Nationality and Culture as Factors Influencing Creativity Levels in Candidate Teachers: A Comparative Study between the United States and Turkey, in *BCES Conference Books*, Sofia, Bulgaria, **16**, pp. 59–67, 2018.
71. V. P. Glăveanu, Measuring creativity across cultures: Epistemological and methodological considerations, *Psychol. Aesthet. Creat. Arts*, **13**(2), pp. 227–232, 2019.

Hao He is currently a doctoral student from the School of Information Science and Learning Technologies at the University of Missouri-Columbia, with research interests including transdisciplinary creativity, virtual reality learning environment, and game-based learning. He received his BA in English Language and Literature from Zhejiang University City College in China, 2008 and then worked as an English teacher and an instructional project manager for seven years. He received his Med in educational technology at the University of Missouri in 2017. In the same year, he started his doctoral study. During his master's and doctoral studies, he conducted studies including creativity in engineering education, blended learning in bioengineering education, virtual reality learning environment, and usability study.

Johannes Strobel is the director of STEM & CS Education at SRI International. He was a Full Professor at the School of Information Science & Learning Technologies at the University of Missouri, where he conducted research studies in engineering and STEM education. His research focuses on engineering and STEM learning through hands-on and online activities; and defiance, empathy, care, and worldviews in engineering. Dr. Strobel received the 2018 Science Educator of the Year Award from the Academy of Science – St. Louis and the 2018 STEM Excellence Award from the International Society for Technology in Education (ISTE). He founded the Journal of Pre-College Engineering Education Research (J-PEER).

Suzanne Burgoyne is a Curators' Distinguished Teaching Professor Emerita and Director of MU's Center for Applied Theatre and Drama Research, where she investigates the use of theatre techniques as active learning pedagogy for other fields. She has been co-PI in three major MU grants that use interactive theatre: Ford Foundation Difficult Dialogues, NSF ADVANCE, and Susan G. Komen (the last in collaboration with MU's Medical School). She has held two national interdisciplinary fellowships: a Kellogg National Fellow (leadership training and interdisciplinary research) and a Carnegie Scholar (scholarship of teaching and learning). In 2011, she attended a summer institute at the Alan Alda Center for Communicating Science. Since then, Suzanne has conducted communicating science workshops using actor-training techniques to enhance presentation skills; and collaborated on an MU NSF grant: "NRT-IGE: A testbed for STEM graduate student communication training," 2015–2018. Suzanne is co-author with Bill Timpson, a member of her Kellogg cohort and Professor of Education at Colorado State, of Teaching and Performing: Ideas for Energizing Your Classes. Her book, *Thinking through Script Analysis*, embeds learning of higher-order thinking skills, including critical and creative thinking, into the disciplinary content. Suzanne edited *Creativity in Theatre: Theory and Action in Theatre/Drama Education*, Volume 2 of the *Creativity Theory and Action in Education* series (series co-editor Ronald A. Beghetto). Suzanne is a Co-PI on the grant.

Joshua Saboorizadeh is from St. Louis, Missouri, and a proud Iranian-American theatre artist and scholar. Joshua believes theatre education can be used as a tool to interrogate the inequitable and ignite unapologetic curiosity. Joshua has previously helped teach creativity courses for the honors college and the bioengineering department at Mizzou, presented at the Pedagogy & Theatre of the Oppressed Conference, and Association for Theatre in Higher Education Conference. Josh is a graduate student researcher on the grant.

Heather K. Hunt received her BS in Chemical Engineering from Iowa State University in 2004. She worked in the petroleum industry and performed industrial research in polymers and composites prior to obtaining her MS and PhD in Chemical Engineering from the California Institute of Technology in 2007 and 2009, respectively, in the research group of Prof. Mark E. Davis. She was awarded an NSF Graduate Research Fellowship for her doctoral work. After graduating, she joined the research group of Prof. Andrea M. Armani, in the Mork Family Department of Chemical Engineering and Materials Science at the University of Southern California, as a Postdoctoral Scholar. In 2011, she joined the faculty as an Assistant Professor in the Department of Bioengineering at the University of Missouri, and in 2017, was promoted to Associate Professor with tenure. She previously served as the Director of Undergraduate Studies for the Biomedical and Biological Engineering degree programs in the Department of Biomedical, Biological & Chemical Engineering. Currently, she is the PI on an NSF REU Site, entitled, "REU: Creative Approaches to Materials Design and Processing." She has also served as an elected Councilor-at-Large for the Institute of Biological Engineering and as the Conference Chair for the 2018 and 2019 Institute of Biological Engineering's Annual Meetings.

Ferris Michael Pfeiffer earned his PhD in Mechanical Engineering from the University of Missouri. He is now a Mizzou Advantage Scholar in the One Health/One Medicine focus area. His research focuses on understanding orthopedic tissue adaptation utilizing laboratory and computational models. Additionally, as head of Biomechanics and Bioengineering at the Comparative Orthopaedic Laboratory, he is intricately involved in the development of multiple orthopedic treatments, including anterior cruciate ligament repair and fixation, cartilage preservation and transplantation, and detection and treatment of osteoarthritis.