On the Potential Role of Artistic Process Workshops to Develop Creative Thinking Skills of Engineering Students: Preliminary Results and Insights

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Abstract

To develop the creative thinking skills of engineering students, a series of workshops taught by practicing artists were organized. The workshops lasted 90 minutes and were roughly divided into three main segments. During the first segment which lasted 15-30 minutes, the practicing artist discussed their artistic processes and described how they make new work using this process. During the second segment, which lasted 45-60 minutes, the students attending the workshop experimented with one or more of the artistic processes introduced by the artist to generate concepts or create artifacts. During the third and last segment, which lasted about 15 minutes, the workshop participants presented and shared their work with the rest of the workshop participants. Upon the conclusion of the workshops, participants were invited to respond to a survey to reflect on their experiences of the workshops. They were also asked whether they would want to participate in a follow-up interview to probe deeper into their responses to the reflection prompts.

To date, four creative thinking skills development workshops have been delivered. One-on-one, semi-structured interviews were conducted with three participants from the first workshop in the series. The interviews were audio recorded and transcribed verbatim. Interview transcripts were qualitatively analyzed using open coding. This paper presents some preliminary insights on the experience of engineering students as participants of creative thinking skills development workshops offered by professional artists and the engineering students' perceptions on the potential benefits of such workshops to engineering education and practice are also discussed.

Keywords. Creativity. Engineering. Artistic process. Alternative Uses Test.

Introduction

Artificial intelligence-enabled technologies are increasingly automating simple, common, repetitive tasks liberating engineers to perform complex, unusual, novel tasks and giving them the time to innovate and create products, processes, and systems to improve human lives. In this context, creative thinking emerges as an increasingly more important core competency for the engineering workforce. Currently, although creativity is deemed to be important in engineering [1, 2], creative thinking skill development is addressed haphazardly or not at all in engineering education.

Evidence suggests that personality traits that are related to creative characteristics and behaviors (e.g., out-of-the-box answers to standard questions) are not favored in classroom settings that are designed for prescription and standardization that rewards conformity [3, 4, 5]. Furthermore, there is a recognition that traditional engineering education approaches do not necessarily nurture the creative problem-solving skills needed in engineering practice [6, 7].

Incorporation of broader use of idea generation techniques, assignment of open-ended and underdefined problems, and creating an educational environment that is welcoming to creative characteristics and behaviors have been suggested [7, 8, 9]. A more recent stream of literature proposes and investigates the incorporation of arts-based pedagogies into engineering curriculum to support the development of creative thinking skills of engineering students. Such initiatives span a broad spectrum from the development of courses that enroll students in engineering and design for an interdisciplinary exploration of a specific engineering topic (e.g., composites design in [10] to development of workshops oriented towards PhD students to help them think more creatively about their dissertation topics [10] to development of concentration areas with multiple courses to facilitate the interaction of engineering and arts students and enable aesthetically informed technological innovations [11].

To support the development of creative thinking skills of engineering students in Herbert Wertheim College of Engineering at the University of Florida, a series of workshops led by practicing artists were planned. The fundamental art pedagogy centers around four distinct elements: (i) demonstration and/or lecture, (ii) hands-on experience, (iii) critique, and (iv) exhibition [12]. Each workshop was designed to include these four elements of art pedagogy. To ensure the representation of different domains, practicing artists from different domains in visual and performing arts have been invited. To date, four workshops have been delivered by artists in theater, painting, comic making, and contemporary dance making, respectively. The preliminary results reported in this paper rely on the exploration of the data collected after the first workshop led by an artist in theater.

The remainder of this paper is organized as follows: In the following section, the structure and the administration of the creative thinking skills training workshop are discussed, and data collection tools are described. Next, a summary of the findings from the survey and interview studies is provided. The following section describes the data analysis approaches in the current study. Some preliminary insights into how workshops led by practicing artists can be utilized to support the development of creative thinking skills in engineering education are provided. The last three sections discuss the limitations of the study, make some recommendations for implementation, and offer concluding remarks, respectively.

Data Collection

IRB Approval. The data collection and analysis methods for the study were approved by the Institutional Review Board (IRB) at the University of Florida as exempt (Protocol Number: ET00021093).

Workshop. The data for this study was collected during the Fall 2023 semester at the first of a series of four workshops organized by the Engineering Innovation Institute that provides innovation and entrepreneurship education to students in the Herbert Wertheim College of Engineering at the University of Florida. The workshop was offered on a Wednesday from 4:00-5:30 pm. A total of 16 students participated in the event, four of whom were members of the student organization that helped coordinate the workshop. The students who participated in the event either out of curiosity after hearing about it through word-of-mouth or to obtain partial credit for a course they were enrolled in through the Engineering Innovation Institute.

The workshop was led by one of the co-authors (BR) who has a background in theatre where they have served as a director, writer, and performer in a variety of different artistic projects.

The topic of the workshop was "source media," and a demonstration of how different source media can serve as inspiration for innovation the way the practicing artists use source media as inspiration for their theatrical performances for "devised theatre". Devised Theatre is a type of theatre that focuses on creation. In a traditional performance process, the content of the work has already been created at the start of the process. In a devised work, the ensemble starts with the other collaborators on the project and from there creation of a performative work begins.

In this workshop, a creation method of source media was utilized where the participants were invited to look at the inherent performativity of various objects and how in a devised process those objects could be used to create a totally new performance. In practice, the same principles were used, but instead, the emphasis was placed on how those objects could be used as a starting point to innovatively create an enhanced or completely new object that could function more effectively than the original object. The workshop was completed in three main steps:

1. *Introduction*: The participating artist introduced themselves and showed a few brief YouTube videos that demonstrate the use of a source object to inform performance. The source object the artist focused on in their introduction was a mirror. The videos showed how the mirrors were used in various ways such as to show reflections, to direct paths of light, as clothing, and more. Then the artist engaged in a discussion with the engineering students classifying the function of mirrors, both the literal function and the connotative functions of mirrors in society. This introductory exercise primed the students to begin thinking deeply about their source objects so that they would be able to fully understand their object in a literal and metaphorical sense which would aid them when creating new objects that in some way enhance the function of the original object.

2. *Workshop Material:* In the workshop, the artist split the workshop material into two subsegments:

    a. *Warm-up*: The students were invited to stand in a circle and play a game called 'Go, Bazumba,' which starts with the group passing an imaginary ball around the circle, much like the telephone game. Once the students understood the rules of the game, the artist then introduced additional layers or rules to the game that affected the play in some way. Some of these layers included changing the direction of the ball, switching places with other students, making specific vocalizations, and more. As additional layers continue to be added, the game becomes more complex than its original passing of the imaginary ball. This exercise was used to teach the students how to use the principles of the original rules of the game to create more layers that while unique still resonated with what was already established. The game then finished with a few of the participants creating their own layers to add to the exercise.

    b. *Object selection and discussion*: The artist and the workshop coordinators brought several objects and laid them on a table. The objects included a massage roller, a pocket watch, a useless box, a glass measuring cup, a piggy bank, and playing cards, among

other things. Next, the workshop coordinators separated the students into groups. The groups were then given around ten minutes to choose an item, determine the item's literal function and its societal and metaphorical connotations, and create a plan to either enhance the object or create a completely new object based on its original object's function.

Next, the groups were invited to pick a second object and repeat the process. The groups were given the option of combing their two source objects into one new creation, or to fully start over with their new product. Students were also given less time to work with their second object than they were given with their first. The goal of repeating the exercise with less time was to fully instill the concept of creating from source media as well as to allow students to engage in non-judgmental idea generation.

3. *Presentation*: The groups were encouraged, but not required, to come to the front to share their improved product ideas. In total, five different groups shared their new product ideas. Their ideas prompted discussions from the artist as well as the other students in the workshop. This feedback and discussion process is like a feedback process that would be found in a devised theatre process as well as in a product development process where others could share their observations on each project to fully refine each idea.

Upon the conclusion of the workshop, the participants were invited to respond to an anonymous survey that inquired about their opinions at the end of the workshop, two days after the workshop, and a week after the workshop. They were also asked to share their contact information if they were interested in participating in a follow-up, one-on-one semi-structured interview.

***Data Collection Tools*.** Two types of data collection tools were utilized: a survey and one-on-one semi-structured interviews.

The survey had three distinct sections focusing on (i) demographic and biographic information, (ii) the engineering identity scale, and (iii) the workshop experience. They were also asked to share their contact information if they were interested in participating in a follow-up, one-on-one semi-structured interview. Table A.1 in Appendix A provides the list of survey questions.

The interviews focused primarily on inquiring about the participants' experience during the workshop and their opinions about the relevance of creative thinking skills in engineering. The interview questions were categorized into five distinct sections (i) demographic and biographic information; (ii) feedback about the survey; (iii) feedback about the workshop; (iv) feedback about their experience with creativity in engineering education and practice; and (v) interview wrap up. The interviews lasted about 30 minutes. All interviews were conducted by one of the authors (EA) via Zoom® and audio recordings were made. The audio recordings were transcribed verbatim. The transcriptions were de-identified by removing all identifiers (names, locations, institutions, etc.) and associated with pseudonyms that were selected with each participant at the beginning of their interview. The participants were compensated for their participation, Table B.1 in Appendix B provides the interview guide.

Positioning with Respect to the Broader Field of Creativity Research. Rigid thinking is a thinking style characterized by inflexibility, difficulty dealing with ambiguity, and stress when expectations are not met. Rigidity in thinking poses a challenge in effective problem solving. If a problem solver needs to use, or conceive of a way to use, an object in a new, or unusual, or unorthodox way to solve a given problem but they cannot think of such a way, then they cannot solve the problem because the problem solver demonstrates a *fixed* way of thinking about the function of the object. This phenomenon is known as *functional fixedness* [13]. Functional fixedness is a type of cognitive bias that may impair creative thinking, if the problem solver cannot think of using the object in a new function that is required to solve a given problem. One way to overcome functional fixedness is to practice divergent thinking [14, 15]. The Alternative Uses Task (AUT) (e.g., [14] and the references therein) is often used as a divergent thinking measurement, invites a subject to think of as many uses as possible for a simple object, like a brick or a shoe or a paper clip under a time constraint of 2-3 minutes.

AUT is sensitive to the differences in the stimulus modality [16] as well as the task instructions [17]. For instance, providing the picture of an object versus the name of the object changes the responses. The segment of the object discussion activity in the workshop investigated in this study is like the AUT, but two major differences: (1) the participants were given physical objects that they can explore by their senses and (2) the participants were asked to determine the object's basic function(s) along with its societal functions and metaphorical connotations. By giving the participants physical object by asking the participants to think of the societal function of an object, the workshop facilitator invited participants to expand their thinking to include the societal context beyond one's individual experience. Furthermore, by asking the participants to think of metaphorical connotations, the workshop facilitator invited participants to further expand their thinking and dig deeper into their imaginations via metaphors.

Results

Survey Study. Sixteen students participated in the workshop, four of which were members of the student organization that coordinated the event. These 4 students did not respond to the survey. Out of 12, 10 students started the survey, but 6 of them completed the survey, i.e., survey participation rate is 50 percent. Out of 6 students who completed the survey, 5 students responded to the open-ended reflection prompts. The demographic and biographical information for the 6 participants who completed the survey are presented in Table 1.

Table 1. The demographic and biographic information of the participants in the survey study.

Factor	Levels	Count
Gender Identification	Male	4
	Female	2
Racial Identification	White	4
	Asian or Pacific Islander	2
Age	21	1
	22	1
	23	1
	25	3
Major	Aerospace	2
	Computer Science	2
	Industrial and Systems	1
	Mechanical	1
Degree Program	BS	2
	MS	3
	PhD	1

The Engineering Identity Scale [18] was also used to collect additional data to understand whether participants would self-describe themselves as engineers. However, during the implementation of the survey, one of the items was accidentally omitted. Hence, the results are not reported in the main body of the paper (see Appendix B for additional information).

***Interview Study*.** Out of the 5 students who responded to the open-ended reflection prompts, 3 students expressed interest in follow-up interviews.

The demographic and biographical information for these 3 participants is presented in Table 2. All three participants have a computer science background. While Ash was a computer science major before she switched over to industrial and systems engineering, Bob and Victor completed their undergraduate programs in electronics engineering and information technology, respectively.

Table 2. Participant: Demographic and Biographic: Age, gender identification, degree program and engineering major.

Name	Age	Gender identification	Degree Program	Current Major
Ash	21	Female	BS	Industrial and systems engineering
Bob	25	Male	MS	Computer science
Victor	25	Male	MS	Computer science

The prior workshop attendance and work experience as well as the extracurricular interests of the participants are summarized in Table 3. All three participants had work experience commensurate with their degree program. While Ash was a co-op student and had two internships, Bob and Victor held full-time engineering positions upon the completion of their undergraduate degree programs. Furthermore, all three participants were involved with sports and occasionally participated in recreational team sports. Furthermore, Ash and Victor were interested in vocal music, and Victor had received 5-6 years of formal training. In our sample, Victor was the only individual who participated in similar workshops where practicing artists shared their creative thinking and making processes with participants.

Table 3. Participant: Background: Prior creativity training, prior work experience, and extracurricular interests.

Name	Extra-curricular	Prior work experience	Prior workshop experience
Ash	Recreational sports. Music (vocals).	Co-op: Warehousing; Home appliances. Internship; Manufacturing; Household products. Internship; Data analytics; Bank.	No
Bob	Recreational sports.	Embedded engineer; Consumer electronics.	No
Victor	Recreational sports. Music (vocals).	Operations and development engineer; Robotics	Yes

The prior experiences that the participants had where they had to and/or could practice and demonstrate creativity could be categorized into two main domains of educational coursework and professional work. As shown in Table 4, all three participants had experienced creativity during their education and in their practice.

Table 4: Participant: Experience: Creativity in coursework and creativity at work.

Name	Experienced creativity in coursework as an engineering student	Experienced creativity at work as an engineering practitioner
Ash	Yes	Yes
Bob	Yes	Yes
Victor	Yes	Yes

Data Analysis

Interview data was analyzed qualitatively using open coding [19] by one of the authors (EA) focusing on the participants' experience at the workshop and their perspective on creativity. Findings related to the participants' opinions about the workshop experience (Topic 1), their prior experience in similar workshops taught by practicing artists (Topic 2) as well as their experiences and opinions about their experiences of demonstrating creative thinking skills in their coursework throughout out their engineering education (Topic 3) and their work as engineering professionals (Topic 4) as well as some suggestions from the participants (Topic 5).

Topic 1: Workshop Experience. As can be seen from Table 5, Ash participated only in the first three sections of the workshop, whereas Bob and Victor were present throughout the entire workshop.

Table 5. The objects picked by the participants' working groups for ideation and the idea presented at the end of the workshop.

Name	Artist's Introduction	Warm-up Activity	Ideation: Object 1	Ideation: Object 2	Presentation: Idea object(s)
Ash	Yes	Yes	Pocket watch	N/A	N/A
Bob	Yes	Yes	Glass measuring jug	Massage roller	Glass measuring jug
Victor	Yes	Yes	Useless box	Pen	Useless box and pen

Warm-up Activity. All three participants expressed qualms about the warm-up activity when they were given the instructions for it. For Ash, her hesitancy appeared to depend on whether others would participate or not. But as others participated in the activity, she "ended up having a lot of fun," and she thought that the activity was "very cool" and "great." Next, Bob's hesitancy was

due to his apprehension towards "exposing" and "opening himself to others" but was able to come out and do a lot of things," and he "could see (his) change from the starting of the activity to the mid activity and by the end of the activity." Finally, Victor self-described himself as "not being open to new people" and "not being the center of people's attention." Hence, he was not excited about it but the activity "took out the fear out…and helped us lose all inhibitions," and said, "it was a bit goofy but I really enjoyed it as it went by." It appears that the warm-up activity was to create an atmosphere where participants felt comfortable sharing their thoughts and opinions easily.

Ideation with Objects. All three participants described how the group's ideation process unfolded. In what follows, summaries of the participant's recollection of the ideation process in their working groups are provided.

Ash's group picked a pocket watch. In the beginning, the group focused on different tasks that can be timed. Then Ash suggested picking apart the watch and coming up with things to do with the components. Although this is high-level divergent thinking to use a given object as an input to design another object, the other members of the group agreed that "that was not the point of this workshop." However, this proposition was perceived to be "so out of the box" that it gave the agency to other members of the group to broaden their thinking and start thinking of other uses for a pocket watch other than measuring time. The idea the group presented was to give a pocket watch as a graduation gift to those who obtain PhDs in industrial and systems engineering, as methods and time measurement is one of the areas that have given rise to the discipline of industrial and systems engineering.

Bob's group picked a clear glass measuring jug as their first object. In the beginning, the group focused on different uses related to food making (e.g., measuring liquids in cooking) and consumption (e.g., using it as a mug to drink coffee). Then, the group suggested using it as a tool to draw circles or as a paperweight. Next, the group focused on material technology to further improve the product (e.g., making the glass photosensitive so that the glass changes color depending on the temperature of the liquid inside). Bob also mentioned that when the practicing artist stopped by their table and validated their opinions and invited them to think of more things to add. As a second object, Bob's group picked a massage roller. Since they were doing it a second time, Bob stated that the group came up with a lot of different uses in different contexts by different individuals, such as a child using it as a toy or as an individual using it as an assistive to help move a heavy box.

Finally, Victor's group picked a so-called Useless Box, which is a box with a switch on it. When one hits the switch the lid of the box opens and out comes a hand that turns the switch off closing the lid back again. Victor recalled that the group came up with many ideas in a collaborative manner, but the group settled on presenting the idea of using the useless box as a piggy bank as it would also help protect the coins or bills put in by design. Victor's group picked a pen as a second object. He did not remember much about the discussion of the second object but remembered how the group considered integrating the two objects and suggested using the pen as a defensive tool in case someone tried to break into the piggy bank.

All three participants mentioned that they themselves participated in the ideation process actively and noted that they enjoyed the process and thought that it was fun.

***Topic 2: Prior Creativity Training*.** In this preliminary sample, Victor is the only participant who had participated in similar workshops before. Interestingly, he attended such workshops when he was still in high school. Since it had been a long time since he participated in those workshops, he could not recall during the interview the exact number and/or the content of these workshops but he mentioned that they were delivered by practicing artists also. He noted that the artists made presentations about their creative processes in the arts and talked about how creativity "helps tune one's mind into thinking differently" and "ties into (one's) work and daily life."

***Topic 3: Creativity in Coursework*.** All the participants in this preliminary sample could give examples of engineering courses they took throughout their undergraduate and/or graduate education where they were allowed to demonstrate and develop their creative thinking skills.

Ash recalled two courses throughout her undergraduate education at the University of Florida in the United States where she was asked to demonstrate her creative thinking. One was a computer programming course where students were given a specific assignment and were invited to add any features that they wanted or were interested in into their basic code. About this experience, she noted, "…where you can just kind of put your own twists on it and then instead of getting like penalized for messing it up, it would be more rewarded for being creative." The other was an inventory management course where she was asked to edit given poems or create her own poems on technical topics. About this experience, she stated that this experience of writing poems, "was a lot of fun."

Bob recalled that "the kind of assignments given" in programming courses he took during his undergraduate and graduate program required him to be creative. Such assignments asked you to utilize "some different thought processes or different ways to get you a solution." Like Bob, Victor also noted that several programming courses throughout his graduate education, where he was asked to demonstrate and practice his creative thinking skills. However, he recalled another course from his undergraduate education in a different country, where the first year of the engineering curriculum is the same for all majors. In this curriculum, there was an electrical and electronics course during the lab in which the students were given a home appliance and all the required circuitry, and the students had to make the appliance work and fix any issues if there were any. He stated "these (…) brought the creativity in me, and this definitely did help me further in my undergrad studies" and added that "when you're given a circuit board and an appliance where wires are just hanging around…you really don't know what to do with them. And you just think of ideas, all kinds ideas, of what you can do with those wires, where to place them on a circuit board and what goes where and trying different combinations and making sense of those combinations finally brought us to first to the result. So…creativity did really help."

Topic 4: Creativity at Work. As can be seen from Table 2, all participants had work experience, and all three mentioned that during their work experience, they were assigned tasks where they had to be creative.

When asked if her past co-op and internship experiences supported the development of her creative thinking skills, Ash said, “a hundred percent.” She said that she was assigned different projects on things that she knew nothing about, and she “had to really think about ways to go about certain things that I had never done before or had never been taught to do before,” which got her adaptive or improvisational thinking skills. Similarly, Bob also noted that his regular work in his full-time job as an embedded engineer required him to “think or do some brainstorming on (how) to get your things done” when he encountered an irregularity in the process that required the engineers to adapt and modify their work. Lastly, Victor said that, in his role as an operations and development engineer in a start-up in the robotics and electronics sector, a lot of work he did was related to trending technologies, and, hence, was novel. In his role, he was asked to explore some of the competing products and find ways of how to “integrate it into our project and see where we can go with it” in his work in a start-up company.

Topic 5: Suggestions. All three participants expressed enthusiasm about the opportunity to participate in this workshop and noted that they would have liked to have more opportunities to develop their creative thinking skills.

Ash noted that there will always be students who “don’t really care and don’t want to show up” in such creative thinking development workshops. She expressed her support for “trying to include more” of these workshops for students, and went on to say, “I hate the word mandatory, but something along the lines.” She stated that “hearing other people’s perspectives on how to approach different problems” could be eye-opening and added that “I could have completely missed this idea if someone else hadn’t put it into my attention.”

Bob said that creative thinking skills development should be “like a norm” and “a part of our regular assignments” where students could be given “…some task and I don’t know what kind of task but some task, kind of things can be given, which could help increase, improve creativity” so that it could be part of one’s daily life.

Finally, Victor said “I would expect you to do more of these (workshops)” He added that the integration of creative thinking skills development into the course curriculum would be more useful. With some reservation, he said “if there's a workshop out there, I'm telling you from student perspective, honestly, people might not go for it. Unless they're really, really interested. But if you put something like this into a course, then there students are in a way forced to have this, have to attend this.” He went on to say, “…for some (people) who are not that interested or don't really know or don't realize how useful creativity and innovation are to engineers out there.”

Discussion: Preliminary Insights

The idea of inviting practicing artists to deliver workshops on their artistic and creative processes to engineering students is not new. In fact, one of the participants attended such workshops as a high school student in his home country. However, it is not clear how such workshops can be integrated into existing engineering education programs effectively and sustainably.

In terms of the workshop format, two observations can be made. One, the warm-up activity was received well by all three participants as it helped them to overcome their reservations about freely expressing their opinions and generating ideas without worrying whether they were silly or bizarre. Two, during the object selection and discussion activity, the artist walked around the classroom to listen to the conversations of the groups one at a time. During these brief visits, they not only expressed their appreciation of the ideas generated by the group thus far but encouraged the group to generate even more, bigger, and bolder ideas. All three participants noted the positive impact of these brief "coaching" moments on their group's discussion process.

In terms of the role and relevance of creativity in engineering, all three participants highlighted the importance of creative thinking as a critical skill in engineering. All three of them were asked to demonstrate creativity in solving new problems in their roles as engineering practitioners. Furthermore, although they all had some experience with demonstrating creativity in their coursework throughout their engineering education, they expressed a need for additional training in creative thinking. Although they all enjoyed participating in the workshop and noted that they would be willing to participate in similar workshops, they advocated for the integration of creative thinking skills development into regular coursework so that it becomes a standard component of engineering education, making it part of each engineering student's educational experience by design and not just for those students who seek it out actively.

Limitations

A limitation relates to the number of participants included in the current study. As each participant raised different points, the research team believes that data saturation has not been reached and that there is a need to expand the sample size. In addition, although three creative thinking skills development workshops have been delivered to date, only the participants in the first workshop expressed an interest in participating in the research study. This may be in part because a participant must complete the entire survey before expressing their willingness to participate in the interview study. Furthermore, there was neither a reward for completing the survey nor a penalty for not completing it. Hence, the survey response rate to date has been relatively low. However, starting with the third workshop, the research team decided to adjust the interview study participant recruitment strategy by reaching out to the workshop participants directly. In fact, at the time of the preparation of this manuscript, one additional participant from the third workshop expressed their interest in participating in an interview. It would be beneficial to recruit 2-3 participants from each workshop to generate a holistic understanding of the workshop series.

Another limitation relates to the majors represented in the participant sample. Two of the participants are in computer science. Although Ash is currently an industrial and systems engineering major, she noted that she had started in computer science as a freshman and had changed her major later. Hence, the sample has a bias towards computer science, which appears to have creativity inherently embedded into the major. During her interview, Ash said that engineers in computer science "…have kind of a luxury of where they have to be creative with their code because if two people submit the same exact code, then it's cheating from each other. But for a lot of the other different majors, I feel like it's lacking in that like individuality…" This raises an important question of whether majors and/or courses that are heavy in computer

programming develop the creative thinking skills of the students more than majors and/or courses that do not rely on computer programming as much. It would be beneficial to further probe into this topic via purposeful sampling.

Another limitation relates to the reliance of the current study on the memory and recall of the participants. In the future, it could be beneficial to obtain consent before the workshop and video record the entire ideation discussion of a group to examine how ideation evolves.

Recommendations for Implementation

A detailed script of the workshop delivered by a professional theater artist and director is provided in this manuscript. This script can serve as a blueprint for generic, course-content agnostic, creative thinking skills development-oriented workshops. However, there is an art and science to facilitating workshops such as these and the experience of the participants as well as the output of the workshops depend highly on the skills of the workshop facilitator. While this manuscript aims to describe the mechanics of organizing such a workshop, persistent experimentation with the workshop is needed until the facilitator gains sufficient experience with the intended audience to identify common misconceptions, pitfalls, etc. Also, in this study setting, the facilitator engaged with the groups during the workshop. Hence it is suggested that the facilitator engages at least once with each group during the workshop to see the ideas the group has come up with and give the group some pointers to further their ideas using prompts such as "I see you were thinking the meaning of the object in a family or a classroom setting. How about in public transportation or in the space station?"

As workshops that are offered in the evenings may not be well attended, the 90-minute workshop content presented in this manuscript can easily be scaled down to a 60-minute session and integrated into existing courses, e.g., first-year freshmen engineering design and senior design courses. In fact, any engineering course that has a design element or a project component could benefit from the inclusion of such a workshop and provide time and space for students to think more freely and creatively about the design concept or the project problem.

We recommend that the three-step design (including warm-up, ideation, and presentation) of the workshop be retained. The warm-up step serves two important purposes by allowing the participants to get in a playful mood and familiarize themselves with the ideation task. The ideation step, the main element of the workshop, is where the participants practice their idea-generation skills. The presentation step also serves two crucial purposes, enabling the participants to receive feedback on their ideas and give feedback to others. The warm-up step can be completed in 5-10 minutes, whereas the ideation step can be allocated 30-40 minutes. Finally, the presentation step can be scaled down to 10-15 minutes.

Lastly, the approach outlined here can be used in any engineering course. For instance, consider a course on materials. The ideation step could invite students to pick a material type, consider its properties and/or current application areas, and imagine new properties and/or uses for this material. Then, the students could be asked to pick another material type, consider this second material type's properties and/or application areas, and imagine ways on how the two materials

considered so far can be combined or used together to enhance their existing properties and/or lead to new application areas.

Concluding Remarks

To develop the creative thinking skills of engineering students, a series of workshops taught by professional artists were organized by an institute in the Herbert Wertheim College of Engineering at the University of Florida. The purpose of the workshops was to advance students' understanding of the creative processes of professional artists and to develop the students' creative thinking abilities. To date, four workshops led by artists in theater, painting, comic making, and contemporary dance making have been conducted. The data used for the preliminary investigation reported in this paper was collected by conducting one-on-one interviews with three participants of the first workshop. The collected data is analyzed qualitatively using open coding.

Preliminary findings indicate that the engineering students who participated in the study enjoyed participating in creative thinking skills development workshops and thought that they learned and practiced skills that would be useful to their engineering practice. Also, the preliminary findings indicated that although creative thinking skills development is not explicitly incorporated throughout the engineering curriculum, engineering professionals are required to demonstrate creative thinking skills as part of their jobs, indicating a potential skills gap between engineering education and engineering practice. Last but not least, all participants voiced a preference for the incorporation of creative thinking skills development exercises into existing coursework for regular and repeated practice.

The research team aims to recruit additional interview participants to ensure that opinions and perspectives of participants from a wider range of engineering majors who participate in workshops led by artists in various fields different artistic domains are captured by the data set for the study.

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Appendix A: Survey study data collection tool and results

Table A.1 Survey questions.

Block 1: Demographic

1. What is your age (in years)?
2. Which gender do you identify with?
3. Which racial background do you identify with?
4. What is your major?
5. What degree program are you enrolled in?
6. What year of your studies are you in?

Block 2: Engineering identity

Please rate how much you agree or disagree with the following statements.

1. My parents see me as an engineer.
2. My instructors see me as an engineer.
3. My peers see me as an engineer.
4. I am interested in learning more about engineering.*
5. I enjoy learning engineering.
6. I find fulfillment in doing engineering.
7. I am confident that I can understand engineering in class.
8. I am confident that I can understand engineering outside of class.
9. I can do well on exams in engineering.
10. I understand concepts I have studied in engineering.
11. Others ask me for help in engineering subjects.

Block 3: Open-ended questions

1. Please summarize what you learned about Braxton Rae's creative process during the first part of the workshop.
2. Please explain how you applied what you learned about Braxton Rae's creative process during the first part of the workshop to complete the design task you worked on in the second part of the workshop.
3. Please explain what you learned in the workshop with Braxton Rae that might be beneficial to you as an engineering student during the remainder of your time at this large public university and/or an engineering professional in the future.
4. Overall, how would you describe your experience of the workshop with Braxton Rae?

Block: Willingness to participate in a follow-up interview

1. Would you be interested in participating in a follow-up interview? If so, please enter your email address.

* This item was accidentally omitted in the distributed survey.

The participants were asked to respond to 10 items of the Engineering Identity Scale [18]. These items were on a 7-level Likert Scale, and the response choices included *strongly disagree*, *disagree*, somewhat disagree, *neither disagree nor agree*, somewhat agree, *agree,* and *strongly agree*, and assigned scores of 1 to 7, respectively. Since there were 10 items on the distributed survey, the highest and lowest achievable scores were 70 and 10, respectively. Table A.2 presents the total scores aggregated by Gender Identification and Degree Program.

Table A.2. The Engineering Identity Scale scores of participants summarized by Gender Identification and Degree Program.

Factor	Levels	Mean	Range
Gender Identification	Male (4)	65.5	[63, 70]
	Female (2)	64	[64, 64]
	Total (6)	65	[63, 70]
Degree Program	BS (2)	65	[64, 66]
	MS (3)	63.3	[63, 64]
	PhD (1)	70	[70, 70]
	Total (6)	65	[63, 70]

Appendix B: Interview study data collection tool

Table B.1 Interview guide.

Block 1: Introduction: Biographic and Demographic Information

1. Can you please tell me a bit about yourself?
2. Have you taken any workshops like this that are taught by practicing artists?

First, I want to inquire about your experience with the preliminary survey.

Block 2: Feedback on the Survey

1. Was there an aspect of the workshop or your experience therein that we did not ask in the on-line survey that you think we should have included?
2. When you expressed willingness to be interviewed further, was there anything you wanted to talk about your experience at the workshop?
3. When you expressed willingness to be interviewed further, was there anything you wanted to talk about your perspective on the integration of creative thinking skills training into engineering education?

Next, I want to you reflect on your experience during the workshop.

Block 3: Focused Inquiry: Experience During the Workshop

4. Can you please describe to me your experience about the warm-up activity?
   What was your initial response to the activity?
   How did your perception of the activity change throughout the activity?
   What do you think was the purpose of this activity?
5. Can you please describe to me your experience when you were asked to pick an object and discuss it functionality and cultural relevance?
   a. Which object did your group choose?
   b. What can you tell me about your group's discussion about the object?
6. Can you please describe to me your experience when you were asked to pick a second object and discuss it functionality and cultural relevance?
7. Is there anything about your experience during the workshop that we have not asked about that you think we should have included?

Next, I want you to reflect on your opinions and perceptions about the development of creative thinking skills in engineering education.

Block 4: Focused Inquiry: Creative thinking skills in engineering

8. Why do you think developing creative thinking skills is important in engineering?
9. In what ways did your engineering education curriculum or your internship and/or work experience help you develop your creative thinking skills?
10. How do you think participating in this workshop helps develop your creative thinking skills as an engineer?
11. In what other ways can the creative thinking skills of engineering students be developed?

This wraps up my questions.

Block 5: Wrap up

1. Is there anything that we have not asked about the development of creative thinking skills of engineering students that you think we should consider?
2. Is there anything you would like to add before we conclude this interview?

Thank you for taking the time to meet with us and discuss your experiences and your opinions. The information you have provided is invaluable, and we appreciate your generosity with your time and all your insights.