Deliberate Development of Creative Engineers

Lt. Col. Jakob C. Bruhl, United States Military Academy

Lieutenant Colonel Jakob Bruhl is an Associate Professor in the Department of Civil and Mechanical Engineering at the United States Military Academy, West Point, NY. He received his B.S. from Rose-Hulman Institute of Technology, M.S. Degrees from the University of Missouri at Rolla and the University of Illinois at Urbana/Champaign, and Ph.D. from Purdue University. He is a registered Professional Engineer in Missouri. His research interests include resilient infrastructure, protective structures, and engineering education.

Dr. James Ledlie Klosky P.E., United States Military Academy

Led Klosky is a Professor of Civil Engineering at the United States Military Academy at West Point and a past winner of ASEE's National Teaching Medal. He is a licensed professional engineer and the Dean's Executive Agent for Design and Construction at West Point. Led's work is primarily in the areas of infrastructure, subsurface engineering and engineering education.

Deliberate Development of Creative Engineers

ABSTRACT

The ability of engineers to create and innovate is an essential part of delivering design value. The engineering profession has made this clear in *The Engineer of 2020* and it is also a central part of the *Civil Engineering Body of Knowledge, 3rd Edition*. Many programs provide an opportunity for students to demonstrate creativity and innovation in their capstone projects but few provide foundational instruction or opportunities to hone creativity skills throughout the curriculum. Inspired by the need to develop creative and innovative engineers and encouraged by the literature about how the necessary skills and attitudes can be developed through education, this paper describes how creativity has been deliberately and explicitly integrated in a required senior-level civil engineering course. Although early in implementation and assessment, the data suggests that integrating creativity into existing engineering courses is viable, does not detract from the traditional technical content, and is appreciated by students. The authors argue that we must aggressively continue to develop creative skills through targeted actions across our curriculum and this paper suggests potential areas for future development in this endeavor.

THE CREATIVITY CHALLENGE!

This paper encourages all engineering educators to deliberately integrate creativity across our curricula – we must do this now. Creativity and innovation skills are not "nice to have"; rather, they are essential. To accomplish this, we need a change in engineering education culture towards a community that honors and rewards creativity and innovation systematically and early.

Engineering is all about creating – from new ideas and products to discovering improved ways of maintaining and utilizing what we already have. Sustainability, sensors and big data, improved efficiency, safety, and even the beauty of what we create – the challenges facing the modern engineering graduate are monumental and require effective design thinking. To produce great designs, engineers must be innovative. This requirement is as old as engineering itself.

In order to innovate, one must be creative and imaginative.[1] In aspirational documents published by the National Academy of Engineers[2] and the American Society of Civil Engineers[3], the call for developing engineers who possess these skills has been clearly made. Beyond the mandate of our professional societies, there is also the clear mandate to be inclusive in all we undertake. Recent studies suggest that creative freshmen students are either leaving engineering to pursue other interests, or are degrading their creative abilities by the time they are senior engineering students.[4,5] To reverse this trend, we must create opportunities for student expression and demonstration of skills beyond simple computation and to make these opportunities available early in the curriculum, so that every student can see where they are adding value to the process *before* deciding that engineering just isn't their thing and changing majors. If all the creativity and innovation are late in the game, some players might leave before the end of the first half. This argument is made in depth by Bruhl and Klosky[6].

Exactly how to develop creative and innovative engineers has been a topic of discussion and study for many years. The third edition of the ASCE Civil Engineering Body of Knowledge states that undergraduate education should provide opportunities for students to acknowledge and practice "professional attitudes relevant to the practice of civil engineering, including creativity, curiosity, flexibility, and dependability."[3] It is clear that these skills are most effectively taught across the curriculum rather in a specific course, isolated from other engineering content.[7] Importantly, the necessary background and skills should be introduced early in the curriculum so students value creativity skills and develop in steps the ability to creatively apply the engineering knowledge they gain.[8] Just like when learning anything, feedback about how well students are demonstrating creativity is vital to their development.[9] To develop creativity, students need to develop traits or abilities, but also must behave creatively which requires imagination and originality. To offer ways for students to practice these behaviors, Ruggiero provides techniques and strategies that can be applied to nearly any engineering course.[10] In his 2017 book written for students, teachers, and practicing engineers, Walesh provides background and practical methods to develop creativity and innovation in engineers.[11]

Even though the need for creative and innovative engineers is not new, many engineering programs do not explicitly address it throughout their curricula. For instance, there are many competitions, challenges and opportunities for the demonstration of design skills, but most are optional or extracurricular, catching only a portion of engineering graduates in a somewhat ad hoc manner and at variable or even random places and times. As Walesh states, "Yes, we could individually and collectively rely on accidental creativity and innovation, those wonderful but rare out-of-the-blue events. However, why not complement accidental creativity and innovation with the intentional kind?"[11(pxviii)] Making development of creativity skills a deliberate part of engineering curricula is vital. If we do not integrate the development of these important skills in our courses, it is likely that many students will not become as creative as they need to and may actually become less creative.

Worryingly, it is also possible that students who arrive in our programs skilled in or valuing creativity may see little concrete benefit or validation of that skill and interest, potentially limiting the pool of creative graduates. Bluntly, students may value what we value and reward – do we as faculty clearly demonstrate the traits and set up reward structures that show our support for creative students? One recent study discovered that incoming freshmen were actually *more* creative than senior engineering students. Among the suggested reasons, the study stated that there is a “definite lack of creativity training within the engineering curriculum, as well as extensive evidence of attrition from engineering majors to other programs.”[4] Examining barriers to innovation and creativity within structural engineering curricula, another team of researchers argued that “focusing predominately on developing analytical skills at the expense of variable solution approaches limits the development of the divergent thinking skills needed for innovation.”[5] In surveying students and faculty perceptions, Kazerounian and Foley found that while engineering instructors report that they value creativity in their students, those students reported the opposite.[12] Zappe and Tise found that while “students perceptions of themselves as creative individuals and their confidence in their abilities to be creative were stable over time” their perceptions of the value of creativity to engineering and the value that their engineering professors placed on demonstrating creativity “was significantly lower in their senior year of study.”[13] There is a clear disconnect between intentions and actions. We need a shift in the

culture of engineering education towards building creative communities that support creative achievement. We must make what is currently mostly extracurricular into a true curricular component.

In order to develop creative and innovative engineers in all engineering programs, faculty and administrators need proven methods to integrate into their courses and curriculum. Since *The Engineer of 2020* was published in 2004, surprisingly few papers have been published to provide such methods. Table 1 summarizes the number of papers in four selected journals, in which the word "creative" or "creativity" appear in the title, in the 16 years since *The Engineer of 2020* was published. Of the 18 published in the *Journal of Engineering Education*, 11 were about creating something (e.g. an instrument, database, or lectures), five described methods to assess creativity within students or their work, and one studied the role creativity plays in academic performance and persistence in engineering programs. Only one focused on teaching creativity within engineering courses. Of the six papers in the *Journal of Civil Engineering Education*, two address developing creativity in students to some degree. There were no papers published in the *Journal of Management in Engineering* between 2004 and 2020 that had the "creative" or "creativity" in the title and the two papers published in *Leadership and Management in Engineering* focused on developing climates to encourage creativity within engineering practice. Of the 26 papers published in these four journals over the past 16 years, only three provided actionable methods to develop creativity within our engineering students.

Table 1 Papers Published Between 2004 – 2020 with "Creative" or "Creativity" in the Title

Journal Title	**Publisher**	**Number of Papers**
Journal of Engineering Education	ASEE	18
Journal of Civil Engineering Education	ASCE	4 technical papers and 2 forum articles
Journal of Management in Engineering	ASCE	0
Leadership and Management in Engineering	ASCE	2

This gap in the literature points to a clear need for faculty who are deliberately integrating creative skill development into engineering courses and curricula to share their findings with the engineering education community. This is currently happening largely through the ASEE conferences in which 179 papers have been published since 2004 with the words "creative" or "creativity" in the title. While many of these are well-documented and carefully studied, some are works-in-progress and others are more accurately reports of something unique that has been tried in the classroom but has not necessarily been rigorously assessed. Richards wrote in 1998 that "as educators we are responsible for stimulating creative thinking among our students … [and] our ultimate goal is to require original creative work as part of every engineering course."[14] We clearly have more work to do to achieve this goal.

A "ROAD MAP" FOR DEVELOPING CREATIVE ENGINEERS

Educating creative engineers requires two primary efforts: (1) deliberately grow creative skills in coherent steps and (2) create community to support and validate that growth. For the first effort, activities and instruction must be tailored towards the development of necessary skills in students early in the engineering curriculum, providing them opportunities to practice those skills and

responding with focused feedback. The second is equally important: we must create communities within engineering programs in which creativity and innovation are showcased and celebrated.

Develop Skills

In a recent paper, the authors provided a few suggestions on how to approach the first effort.[6] These suggestions included:

- Study the outcomes and processes of great historical engineering works,
- Engage in deliberate discussion among faculty about how creativity should find its way into the curriculum, and
- Provide opportunities throughout the curriculum (not just senior year) for students to practice creativity and receive feedback.

The first suggestion is motivated by a common practice in the education of artists – writers, musicians, actors, and visual artists, all of whom study past works in depth. The second and third suggestions are supported by research. For example, to counter the observed trend that the perception of the value of creativity in engineering, Zappe and Tise described that "opportunities for students to engage in the creative process need to be more fully integrated within the engineering curriculum."[13] Regarding feedback, Hennessey and Amabile state that "positive affect leads to higher levels of creativity"[15] and clear, specific feedback plays an important role in developing self-efficacy.

In the previous paper, several examples of opportunities to practice creativity and receive feedback were provided from sophomore- to senior-level engineering courses. In the current paper, a case study is described with student feedback provided. Although this case study does not include efforts to address all three of the efforts above (in fact, it only addresses the third suggestion), it provides valuable feedback from students that can inform other initiatives.

To the list of three suggestions above, we add a fourth:

- Do not use assessment to drive creative action.

One obstacle to creativity and innovation is fear of failure.[11] In other words, in order to be creative, people must be willing to accept the risk of failing. Therefore, if students know they are being assessed on how well they demonstrate creativity, it is likely to reduce the creativity they are willing to include. Graded assessments are high risk events and students are unlikely to try something new or different from what they have previously seen on such an event.

This is not to suggest that creative efforts should not be assessed, but that this assessment should be formative. The importance of feedback cannot be overstated. Creativity is something that many people may be uncomfortable with, particularly when first asked to demonstrate it publicly. The feedback provided must focus on specific skills and include clear instruction for how the student can continue to improve. Importantly, this feedback is most suitably done verbally, face-to-face. Written feedback, like e-mail, lacks the emotional richness that is important in this conversation. Emotional connection can be important, as some students, perhaps most, approach revealing their creative products as a deeply emotional and potentially

embarrassing event. Trust, emotional support and the promise of growth can help to blunt that threat.

The literature includes examples of engineering educators integrating various methods to develop creativity in their students, or at least provide them with opportunities to display creativity. In their paper surveying how creativity and innovation are incorporated into the engineering classroom, Stouffer, Russell, and Oliva summarized examples from a variety of institutions and describe the value that problem-based learning and case studies can provide opportunities to encourage creativity.[16] Shoop and Ressler described a unique elective course for electrical engineering students at the US Military Academy centered around case studies of disruptive and innovative technologies with a goal to develop in students an understanding of how such technologies came to be.[17] Richards summarized several courses from freshman- to graduate-level, required and elective, that were designed to stimulate creativity at the University of Virginia.[14] Teng, Song, and Yuan described a method using software to develop creativity in structural engineering students during the conceptual design phase.[18] To help students understand how iteration in the conceptual design phase of the engineering design process relies on creativity, Gillie, Stratford, and Broadbent describe a method they used in a civil engineering design course which provides a framework for students to use to employ creativity during the conceptual design phase and consider details later in the process.[19] These are all fantastic examples of faculty who have begun to answer the call of developing creative engineers by providing opportunities to practice creativity within the context of engineering projects. What is missing in this list, however, are examples of how to develop the underlying creative skills, abilities, and attitudes necessary for students to be at their most creative when presented with such opportunities. It is important to note that just providing opportunities to practice or demonstrate creativity in projects is insufficient. "Without explicit course design elements related to creative skills within these projects, this project-based approach may not actually improve creativity."[20]

Create Community

Hennessey and Amabile describe how creativity depends on levels of interrelated forces that comprise the individual, groups, and society. These levels can be visualized as a series of seven increasingly large concentric circles, the center of which is (1) neurological and then expands out to (2) affect / cognition / training, (3) individual / personality, (4) groups, (5) social environment, (6) culture / society, and (7) systems approach.[15] The first three of these levels can be addressed by skill development and education about creativity. The next three require a community that values, encourages, and celebrates creativity. If this is lacking, the creativity of the individual will not realize its full potential.

Building a community within engineering programs in which creativity and innovation is showcased and celebrated may sound like a tall order. However, it is essential! As Walesh wrote, "Very few people would intentionally kill creativity or innovation, but many, acting individually or collectively, unintentionally practice ideacide."[21] To prevent this from happening, the culture of an organization must intentionally create the conditions for creativity to occur and flourish. Using an analogy of the theater, Walesh described ways that the leadership of an organization can create a diverse cast and set the stage for creativity and innovation to occur before describing nine specific actions that leadership should take. Several of these relate to building a community

that values, encourages, and celebrates creativity. To be clear: this is a cultural necessity that must be fostered by the organization's leadership.

Too often, our programs hold up one-offs as a sign of programmatic achievement, a sort of "look what that kid did!", but these achievements are singular and were often completed as independent study or extracurricular activities rather than as part of a broad plan for all students. By building a creative community, we suggest that all student efforts are highlighted and successes are honored programmatically. This demonstrates to students and faculty in a meaningful way how important creativity is within the engineering profession and how we are motivated and moved by creative action. Community is built on social networks in which the people practicing the skills are supported and acknowledged. This requires creating time and space: activities must be scheduled and facilities must be provided. Maker spaces, faculty engagement, prizes and prominent display spaces that feature the creators name, like art programs, are concrete signs of the value the institution and its people place in creative output.

One prominent way that many programs are already doing this is with an end-of-year projects day during which students showcase the results of their senior capstone projects. At the authors' institution, this is run almost like a juried art exhibit in which projects are judged and prizes are awarded. Most of the focus of the assessment at the authors' school and at many events like this is on technical merit or communication: does it work and how well did you sell it? It would take little effort to also include recognition for the most innovative solutions presented. It is also worth noting that our projects day comes at the very end of the student's time at the institution, providing only a small forcing function for creativity in the early going.

Another way to create community is by featuring and honoring student creative work during the semester. Similar to how art programs display student work in public spaces throughout the semester, conceptual designs, prototypes, and test results demonstrating creative and innovative work by students could be displayed in engineering departments, complete with student names. Artists sign their work with pride, acknowledging their effort. When students are recognized for academic excellence at award ceremonies, departments should consider awarding students who have taken risks, demonstrated creativity, and striven for innovative solutions.

A nice example of this comes from the electrical engineering program at the University of Texas at Tyler where they created "The Leonardo Project." Electrical engineering students worked with art faculty (writing, music composition, and studio art) to create a portfolio during a one-semester course; this course was in place of a required design methodology course taught in the electrical engineering program. The department celebrated the students' work during a public exposition held in conjunction with the College of Engineering's annual awards banquet.[22] Highlighting the artistic achievements of these students is awesome. Celebrating their creative and innovative engineering efforts would be equally awesome.

The authors are eager to see more examples from others in this realm. We have access to many books on mechanics, treatises on structural design, thick tomes full of equations – exceptional content put together by true experts. We need to develop a similar trove of scholarship, activities and assessment methods centering on creativity; a community of scholars focused on delivering engineers trained in more than computation.

DEVELOPING CREATIVITY SKILLS: THEORY

While there are some people who appear to have been born with unique creative talent, researchers have "found that creativity depends not on the possession of special talents, but on the use of talents that virtually everyone has but most have never learned to use."[10(p96)] It is well established that skills can be taught and developed which enable people to improve their creativity.[14,15,20] Cropley suggests that teachers "should strive to promote in their students:

1. Possession of a fund of general knowledge
2. Knowledge of one or more special fields
3. An active imagination
4. Ability to recognize, discover, or invent problems
5. Skill at seeing connections, overlaps, similarities, and logical implications (convergent thinking)
6. Skill at making remote associations, bisociating, accepting primary process material, forming new gestalts, etc. (divergent thinking)
7. Ability to think up many ways to solve problems
8. A preference for accommodating rather than assimilating
9. Ability and willingness to evaluate their own work
10. Ability to communicate their results to other people."[7]

From the above, there are several that suggest providing instruction and opportunities to practice important skills. For example, item 5 could be developed in students by assigning exercises that ask them to list connections between a variety of images or concepts. As a useful reference for educators, Stouffer, Russell and Oliva summarize proven frameworks and strategies for "fostering creative knowledge skills, and attitudes" within engineering education.[16] Creativity requires more than skills and opportunities to practice. In order to be creative, people must be willing to "[behave] creatively, addressing the challenges we encounter with imagination and originality."[10(p103)] The lesson for educators is that as important as providing opportunities for students to learn and practice skills is the environment in which those opportunities are provided. Because some students will be apprehensive, the environment must be encouraging and pointed, useful, feedback must be provided.

DEVELOPING CREATIVITY SKILLS: CASE STUDY

To provide opportunities for students to develop and practice creativity, one of the authors incorporated creativity exercises in a design of reinforced concrete course. This required course is taken by senior civil engineering students during the first semester of their senior year. It is taken concurrently with the first semester of their yearlong capstone design course in which they work in small teams on unique projects, most of which are for real-world clients. The institution in which this course is taught is a small, public, undergraduate-only institution in the northeastern United States. The civil engineering program graduates about 40 students each year from their ABET-accredited program.

Inspired by ideas from several books on teaching creativity[10,11,23], and one which provides over 150 research-supported activities to develop creative skills[24], one short creativity exercise was included on each homework assignment and even shorter exercises were done in class as a break

from the technical content central to the lesson. Integrating creativity exercises into engineering courses is not a new idea. Weaver and Muci-Küchler summarized three in-class creativity exercises, two of which took considerable time and relied on teams.[25] The in-class exercises in this paper were kept to five minutes or less and were focused on individual accomplishment. The activities described in this paper are more like those integrated by Ask into an introductory mechanical engineering course, which included creating abstract art, writing poems, explaining a painting in words alone, or a thirty-circle exercise.[26]

Prior to the semester beginning, students completed a short anonymous survey to assess their opinions about creativity and innovation before being exposed to discussion in class and exercises throughout the semester. The questions asked in this survey are included in Appendix A. Of the 33 students enrolled in the course, 25 completed the survey. Over 80% of the respondents described themselves as creative and 92% described themselves as innovative. In general, students had a positive and accurate understanding of creativity and innovation. Representative definitions of creativity included:

- "Ability to form unique and independent ideas"
- "Being imaginative"
- "Imagination put in motion"

Representative definitions of innovation included:

- "Able to think outside the box by building upon what is in the box initially"
- "The ability to connect ideas across disciplines in new and productive ways"
- "Applying creativity to problem solving in order to find the best possible answer"

54% of students believed that creativity was something people were born with and 80% thought these were skills that could be developed. The survey also included three images and students were asked to write the first three words that came to mind when they viewed each image. For brevity, results from the response to these three images is not included.

"Creativity!" Program

The program, referred to simply as "Creativity!" was instituted at the beginning of the course. Explanation about why these exercises were incorporated into the course was provided to students in the course syllabus and discussed in class during the first meeting. The explanation provided in the syllabus was:

> "One of USMAs academic goals is to graduate creative and critical thinkers. Our Army needs commanders and staff officers who are creative and innovative (see ADRP 6-0). To assist in developing and expanding your creative mind, each problem set will include a short exercise which research has shown to improve human creativity. See the Creativity! channel on the CE483 Teams site for more details about developing your creative abilities."

Two slides were included in the first lesson to facilitate discussion about creativity and its importance in engineering and do one short exercise to get a sense for the type of activities they should expect during the semester. Note that all students had taken a required civil

engineering course and laboratory experience in the same classroom during the previous semester. The slides are shown in Figure 1.

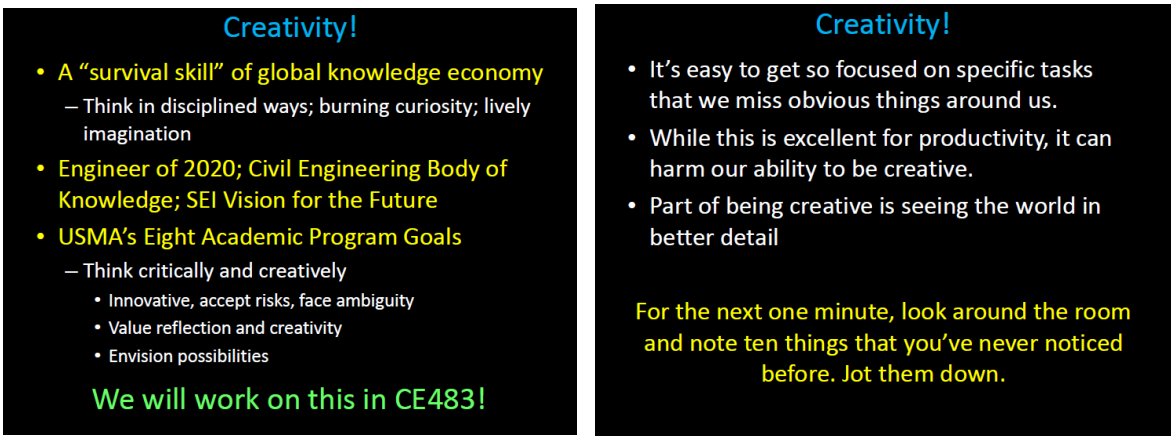

Figure 1 Slides Used in Lesson 1 to Discuss Creativity

Each of the eight homework assignments during the semester included one 10-point exercise (out of 80-100 points total) intended to take 10-15 minutes to complete. Each of these were adapted from a book by Tanner Christensen[24]. In that book, Christensen describes five cognitive categories that influence creativity: convergent, divergent, aesthetic, emergent, and lateral. The author included a variety of exercises to address development of each category. The prompts for each activity included on assignments are provided in Table 2.

In-class exercises were included in nine of the 40 lessons during the semester. Accounting for three field trips, two in-class exams, and two design challenges, in-class creativity exercises were included in 27% of the lessons. The prompts for these exercises are provided in Table 3. Most of these exercises were inspired by Christensen[24] and a few were adapted from other sources. For these, the unique reference is provided. "Old ME404 lesson material" refers to a previous version of the mechanical engineering capstone design course at the authors' institution.

Table 2 Prompts for "Creativity!" Exercises Included on Homework Assignments

Problem Set	Creativity! Prompt	Creativity Area Exercised	Related to C.E.	Could Modify to Relate to C.E.
1	Studies have shown that adding extreme constraints often prompts creative solutions as it forces your mind to focus on the core of the problem. One example is Ernest Hemingway's challenge to write a complete story in six words. In that vein, summarize everything that you have learned in your engineering courses in six words (not six words per course; six words total!)	Convergent	X	
2	Choose a person who inspires you and ask them two questions: (1) What inspires you? And (2) How do you use that inspiration to fuel your own creativity. Write a summary of their answers in a 1-page memorandum.	Divergent		
3	Making remote associations between words or concepts can help you see connections better. Flip to three random pages in the course textbook, select one word randomly from each, and write those three words at the top of a page. Beneath them, write down all the ways those words can be related to each other.	Convergent		
4	Taking time to look for details in the objects or images around us will help your mind begin to see (and eventually imagine) more and more detail enabling you to be more creative. Set a timer for 10 minutes and spend that time carefully investigating the photograph provided in Encl. 2. Make a list of as many small details as you can. This list may be handwritten or typed.	Aesthetic		X
5	Understanding detail can assist in your ability to develop creative solutions. One way to improve this ability is to "deconstruct" existing objects by making a list of everything that goes into it and then making a list of smaller parts and smaller until you get microscopic. Consider a recently built reinforced concrete high-rise building such as 432 Park Ave and create a list of major components, then chose one to make a list of its subcomponents, then chose one subcomponent, etc. For more about the engineering of 432 Park Ave read this, this, and/or this.	Lateral	X	
6	Doodling can help develop your brain by requiring you to translate an image in your mind to the paper in front of you. On a plain white 8.5" x 11" sheet of paper, without being concerned about accuracy, detail, or composition, doodle about things you have learned in CE483 for the next 10 minutes. Remove distractions, set a timer and just doodle.	Aesthetic	X	
7	Explaining something that you know much about to someone who knows nothing about it can help you think about it in a new way. How would you explain how to design a bridge to a child (10 years old or younger)? Write how you imagine the conversation would unfold. Your imagined conversation should be at least one page long but no longer than two pages.	Lateral	X	
8	As with the six word story, imposing constraints to one method of expression can "jolt your creative thinking." Choose one of the following constraints to write a poem about something related to engineering. 1) **Option 1:** Four haiku 2) **Option 2:** Ten-line poem with one-word on the first line, two words on the second line, and so on 3) **Option 3:** Shakespearean sonnet	Convergent	X	

Table 3 Prompts for In-Class "Creativity!" Exercises

Lesson	Creativity! Prompt	Creativity Area Exercised	Related to C.E.	Could Modify to Relate to C.E.
1	It's easy to get so focused on specific tasks that we miss obvious things around us. While this is excellent for productivity, it can harm our ability to be creative. Part of being creative is seeing the world in better detail. For the next one minute, look around the room and note ten things that you've never noticed before. Jot them down.	Lateral		X
2	Listening to music by Mozart has been shown to have a positive impact on thinking ability and increase spatial reasoning skills. Between now and next lesson, listen to the work of Mozart for at least ten minutes. Researchers suggest his sonata K448. (Mozart's sonata K448 was playing in the classroom as students entered)	Emergent		
6	A farmer has 10 trees which he will plant in a square plot. He plants the trees in five rows of four trees each. How did he plant them? Within the next three minutes, sketch how the trees were organized in the square plot.	Source: old ME404 lesson material		
9	Beau Lotto is an astirt who dtceedias his lfie to snohwig jsut how cveirtae our mnids can be. Lotto uess inluslios and scnicee to detamsntroe how our mndis are nltralauy dirven to flil in the blnkas and mkae ssnee of tinhgs, eevn tnghis lkie sacrlembd wodrs. Reesrcah form Cardmibge Uesivinrty has shwon taht Lotto is rghit: Eevn wehn the leettrs of wdros are meixd up, we can siltl uedtnasnrd waht's wetrtin. [24(p119)] Unscramble the words above to turn the paragraph from one made of up seemingly gibberish to one of real words. Hint: the words are already there, you just need to look closely to unscramble them.	Aesthetic		X
12	This is a photo of the Shiosai Bridge, a prestressed concrete stress-ribbon bridge in Shizuoka, Japan. Using your non-dominant hand, sketch the image above (including as much detail as you can). Take 5 minutes. When drawing or doodling with your opposite hand, "the signals between what you see and what you're trying to draw don't match up quite as well … [which leads] to drawings that are more fluid and abstract." This provides a unique opportunity to "spot details in how your perception affects what you're drawing."[24(p74)]	Aesthetic	X	
18	Change the location of only one of the matchsticks below to make a true equality (unequal sign is not allowed).	Source[23(p59)]		
26	Seek out major colors. Look around you and find one object that has each of these major colors: Red, Green, Blue, Purple, Yellow, Black, and White. Ask a friend for help if you get stuck. Many of us are not as observant as we think we are. This means we're missing out on seeing inspiration that may be right in front of us.	Aesthetic		
32	Using only four straight lines, divide the circle into as many parts as you can. You have two minutes!	Source[10]		
37	A bomb has been discovered and the only way to defuse it is place a jug with exactly four gallons of water in it onto a pressure-sensitive switch. Any more or less will immediately detonate the bomb. The only containers you find are a 3-gallon and a 5-gallon jug. In your lab groups, work together to develop a plan to defuse the bomb! You have five minutes	Source: old ME404 lesson material		

“Creativity!” Results

The primary purpose of this initial implementation was to introduce rather than assess students’ creative talents and skills. It focused on how to implement the activities such that students understood the purpose and instructions and identified ways to improve the implementation. In future implementations, the authors will investigate if students’ creative skills change over the semester using creative product assessment methods such as rubrics developed by Brookhart.[27]

Students enjoyed and appreciated the in- and out-of-class exercises and assignments. An anonymous survey was administered near the middle of the semester to determine whether the purpose and instructions were understood for the exercises and to get an idea about how much time students were spending on the exercises and the homework assignments. An open question was also included to provide an opportunity for student-driven feedback. The specific questions are included in Appendix A. The response rate was 57% (19/33 students). Results confirmed that the instructions and purpose for the exercises were clear: all students either agreed or strongly agreed with those statements. Students spent less than 45 minutes on each activity, with the majority (17/19 respondents) spending less than 20 minutes. Open feedback was quite positive. Representative comments include:

- “I think the "Creativity!" exercises are a great way to challenge students. They not only get us to think about things in a non-linear fashion but they also allow us to reflect on other parts of life where we go with "the norm" and fail to exercise creativity.”
- “Love it. Great addition to the course and problem sets.”

There was only one comment suggesting improvement and it was a valid recommendation: “I think that having in-class creative discussion would be beneficial, because we are almost never asked to orate in engineering classes, or to talk about our aesthetic preferences.” Given the time constraints in class, this was not implemented, but is worth considering for future iterations. Overall, the mid-semester data was encouraging and supported further development of the “Creativity!” initiative.

At the end of the semester, as part of the anonymous end-of-course survey administered by our institution, several questions about the creativity exercises were included. The specific questions asked are provided in Appendix A and the results are displayed in Figure 2. The response rate for this survey was 76% (25/33 students). From the figure, it is evident that most students did not have much difficulty completing the exercises although just under half reported that the exercises made them uncomfortable. This was desired: many of our students have not been asked to write poetry in the context of an engineering course, some are uncomfortable with the idea of exposing their own thoughts publicly, and some were likely uncomfortable with there being no specifically correct answer. It is important to note that the grade for their submissions were not assessed for creativity. If the student followed the instructions, the received the full 10 points. They only lost points if the failed to follow the instructions.

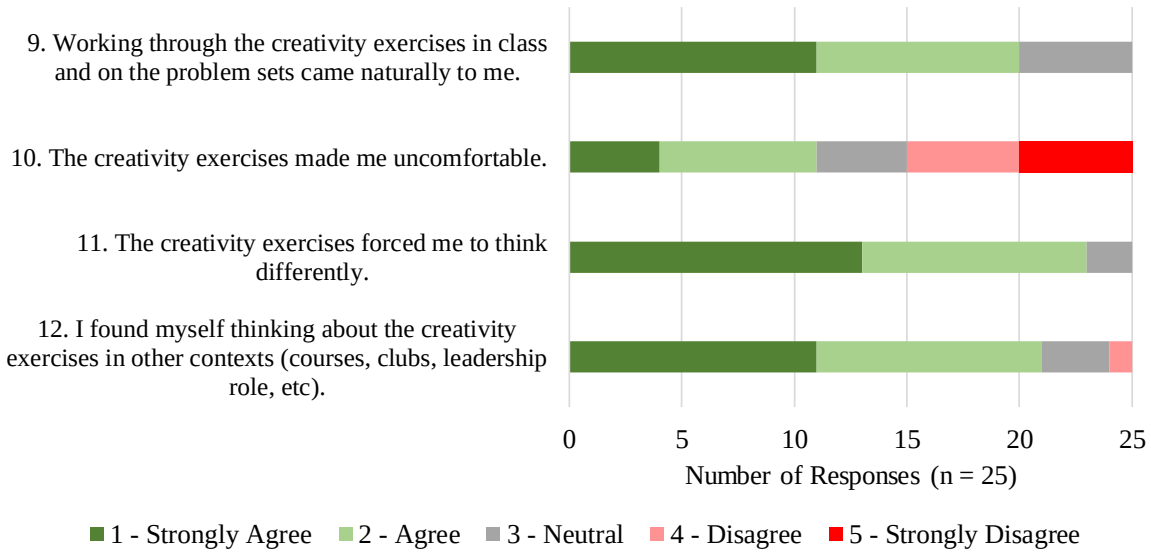

Figure 2 Creativity Exercises End-of-Course Survey Results

The response to question 12 was encouraging: 84% (21 / 25) of the respondents reported thinking about the creativity exercises in contexts outside of this course. This is a very desirable outcome and one that is worth investigating in better detail in future studies. Of particular interest is what they were thinking about in these other contexts: the activity itself or how it might apply in that other context.

There was one open response question asking what students suggest doing differently related to the creativity exercises. Most of the comments were positive: for example, "Nothing, keep them the way they are!" The suggestions for improvements can be grouped into two main categories:

- Do more in-class exercises
    - Representative comment: "Have at least one creativity exercise every two lessons"
- Relate them more directly to course material
    - Representative comment: "I liked the creativity exercises, but maybe make them pertain better to civil engineer"

Regarding doing more in-class exercises, this is challenging because of the time it takes away from covering course material and providing opportunities for students' questions about the technical content. While it is certainly necessary to develop innovative engineers, it is essential that we educate capable engineers. The underlying idea of making creativity exercises more regular is valid, but instructors must be careful that students are still provided with the opportunity to master the important technical content within the course. Striking the right balance requires careful thought and discussion with other faculty.

The second category of comments was interesting. Of the exercises on homework assignments, five of the eight (items 1, 5, 6, 7, and 8 in Table 2) were directly related to civil engineering. Thus, these comments were most likely addressing the in-class exercises. Incorporating this suggestion may actually enable doing more exercises helping to satisfy the desire of students for

more frequent in-class creativity exercises. If the activities are more directly related to course material, they could be used to accomplish two important tasks: (1) provide opportunities to master course content and (2) provide opportunities to think differently and improve creativity skills. The authors are considering how to do exactly this in the next iteration of this project by modifying existing activities (those in lessons 1 and 9 in Table 3, for example) and developing new activities to integrate in class. As a caution, however, Cropley's list which was described previously suggests that having general activities, unrelated to civil engineering specifically, to engage students' minds in other contexts is an important element of creative development.

DEVELOPING CREATIVITY SKILLS: LOOKING FORWARD

We believe the data collected from our initial attempt along with the evidence presented in initial sections of the paper makes a strong case for embedding creativity in engineering curricula formally, starting early in our programs. This initial implementation of creativity exercises within an existing engineering course were very encouraging but was done in a senior-level design course; ideally something similar would be included in the first engineering course students take and then adapted and expanded in courses later in the curriculum. Doing so is important for a few reasons. First, to make clear to engineering students that creativity skills are vital to developing innovative solutions, it is important to introduce this at the beginning of their education. This early inclusion also demonstrates that these are skill sets valued by the teachers/mentors and by the institution. Secondly, to adequately develop skills, students need to practice and grow over a duration longer than a single semester. Third, integrating creativity into most courses helps send the message that these skills are important not only in design projects but more generally to the way they approach and perceive the work of an engineer. Finally, to realize the gains from such a program, the capstone design projects can showcase the innovation that students are capable of, serving as an exemplar and goal for students throughout the program in terms of class year.

While this initial implementation was encouraging, the authors believe that growing creative and innovative engineers would be more effective when it takes place within a community that encourages and recognizes creative efforts and innovative solutions. Having exercises and activities like those described in this paper throughout the curriculum will help in this regard. More importantly, the program must put in place broadly-based events that highlight the work being done by students. In some ways, the civil engineering program in which the authors are faculty is already doing this. An required infrastructure engineering course in the program requires students to create a piece of art near the end of the term that depicts something they learned in the course. The faculty teaching the course judge the pieces submitted and digitally display the top selections on screens in the main hallway of the program. At the end of the academic year, the institution sets a day aside as Projects Day. No courses are scheduled for this day, senior capstone design projects are displayed, presentations are made by seniors, and faculty, students, and people from outside the institution engage with students about their projects. In many ways, this is like an exhibition at the end of an art student's academic career. With a few modifications, Projects Day could also include recognition of the most creative and innovative solutions across multiple year groups and perhaps even programs.

With the success of this initial implementation along with other work on-going in the authors' program[28,29], there is a movement within the civil engineering program at the US Military

Academy at West Point to deliberately make creativity an integral part of the program. These on-going efforts are generating valuable discussion among faculty members and program and department leadership. It is these discussions that will generate even more ideas about how to make the development of creative skills and the celebration of innovative solutions an important and long-lasting part of the culture of the program.

REFERENCES

1. Robinson K. *Out of Our Minds: The Power of Being Creative*. 3rd ed. Chichester, West Sussex, UK: John Wiley & Sons, Inc; 2017.

2. National Academy of Engineering. *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, D.C.: National Academies Press; 2004. doi:10.17226/10999

3. Committee on Education of the American Society of Civil Engineers. *Civil Engineering Body of Knowledge: Preparing the Future Civil Engineer*. 3rd ed. Reston, VA: American Society of Civil Engineers; 2019. https://ascelibrary.org/doi/book/10.1061/9780784415221.

4. Sola E, Hoekstra R, Fiore S, McCauley P. An Investigation of the State of Creativity and Critical Thinking in Engineering Undergraduates. *Creat Educ*. 2017;08(09):1495-1522. doi:10.4236/ce.2017.89105

5. Surovek A, Rassati GA. Is Structural Engineering Education Creating Barriers to Innovation and Creativity? In: *6th Structural Engineers World Congress*. Cancun, Mexico: EERI; 2017.

6. Bruhl J, Klosky JL. Inclusive Teaching: A Call for Creativity (WIP: Work in Progress). In: *ASEE Mid-Atlantic Regional Conference*. New York, NY: American Society for Engineering Education; 2019.

7. Cropley AJ. Fostering creativity in the classroom: General principles. In: Runco M, ed. *The Creativity Research Handbook*. Vol 1. Cresskill, NJ: Hampton Press; 1995:83-114.

8. Walesh S. Creativity and Innovation as Part of the Civil Engineering BOK. In: *American Society for Engineering Education Annual Conference*. Seattle, WA: American Society for Engineering Education; 2015.

9. Cropley DH, Cropley AJ. Fostering Creativity in Engineering Undergraduates. *High Abil Stud*. 2000;11(2):207-219. doi:10.1080/13598130020001223

10. Ruggiero VR. *The Art of Thinking: A Guide to Critical and Creative Thought*. 10th ed. Upper Saddle River, NJ: Pearson Education, Inc.; 2012.

11. Walesh SG. *Introduction to Creativity and Innovation for Engineers*. Hoboken, NJ: Pearson Education, Inc.; 2017.

12. Kazerounian K, Foley S. Barriers to creativity in engineering education: A study of

instructors and students perceptions. *J Mech Des*. 2007;129(7):761-768. doi:10.1115/1.2739569

13. Zappe SE, Tise J. Work in Progress: Engineering students' changing conceptions of the value of creativity. In: *Proceedings of the 8th Research in Engineering Education Symposium*. Cape Town, South Africa: Research in Engineering Education Network; 2019:10-17.

14. Richards LG. Stimulating creativity: Teaching engineers to be innovators. In: *Frontiers in Education Conference*. Vol 3. Tempe, AZ: IEEE; 1998:1034-1039. doi:10.1109/fie.1998.738551

15. Hennessey BA, Amabile TM. Creativity. *Annu Rev Psychol*. 2010;61:569-598. doi:10.1146/annurev.psych.093008.100416

16. Stouffer WB, Russell JS, Oliva MG. Making the strange familiar: Creativity and the future of engineering education. In: *ASEE Annual Conference and Exposition*. Salt Lake City, UT: American Society for Engineering Education; 2004. https://peer.asee.org/13891.

17. Shoop BL, Ressler EK. Developing the critical thinking, creativity and innovation of undergraduate engineering students. *Int J Eng Educ*. 2011;27(5):1072-1080.

18. Teng JG, Song CY, Yuan XF. Fostering Creativity in Students in the Teaching of Structural Analysis. *Int J Eng Educ*. 2004;20(1):96-102.

19. Gillie M, Stratford T, Broadbent O. Creative conceptual design teaching: It's not about rebar curtailment! *J Prof Issues Eng Educ Pract*. 2014;140(3):2013-2014. doi:10.1061/(ASCE)EI.1943-5541.0000184

20. Daly SR, Mosyjowski EA, Seifert CM. Teaching creativity in engineering courses. *J Eng Educ*. 2014;103(3):417-449. doi:10.1002/jee.20048

21. Walesh SG. Staging a Creative Culture. *Leadersh Manag Eng*. 2012;12(4):338-340. doi:10.1061/(asce)lm.1943-5630.0000193

22. Beams DM, Gullings K, Ross CE. Seeking new perspectives: Engineers experiencing design through creative arts. In: *ASEE Annual Conference and Exposition*. New Orleans, LA: American Society for Engineering Education; 2016. doi:10.18260/p.26154

23. Niku SB. *Creative Design of Products and Systems*. Hoboken, NJ: John Wiley & Sons, Inc; 2009.

24. Christensen T. *The Creativity Challenge: Design, Experiment, Test, Innovate, Build, Create, Inspire and Unleash Your Genius*. Avon, MA: Adams Media; 2015.

25. Weaver J, Muci-Küchler K. In-Class Creativity Exercises for Engineering Students. In: *ASEE Annual Conference and Exposition*. Pittsburgh, PA: American Society for Engineering Education; 2008. https://peer.asee.org/3724.

26. Ask T. Engaging Creativity: Classroom Exercises for Enhancing Engineering Students' Creative Self Identity. In: *ASEE Zone I Conference & Workshop*. Niagara Falls, NY: American Society for Engineering Education; 2019. https://peer.asee.org/33791.

27. Brookhart SM. Assessing creativity. *Educ Leadersh*. 2013;70(5):28-34. doi:10.1177/1077695816648866

28. Bruhl JC, Bruhl WG. Engineering Creativity: Ideas from the Visual Arts for Engineering Programs. In: *American Society for Engineering Education Annual Conference*. Montreal, Canada: American Society for Engineering Education (abstract accepted); 2020.

29. Barron C, McCoy B, Case J, Kearby J, Bruhl JC. The Napkin Sketch: A minute-paper reflection in pictorial form. In: *American Society for Engineering Education Annual Conference*. Montreal, Canada: American Society for Engineering Education (abstract accepted); 2020.

APPENDIX A: Survey Questions

Pre-semester Survey About Student Opinions about Creativity and Innovation

1. Write a short definition of the two following words (open response):
    a. Creative
    b. Innovative
2. Rate how well the following statements describe you (likert 1-4):
    a. I am creative
    b. I am innovative
3. Rate how well you agree with the following statements (likert 1-5):
    a. Being creative is important to me as an individual
    b. The ability to be creative or innovative is something a person is born with
    c. The ability to be creative or innovative is something a person can develop with practice
4. Rate how well you agree with the following statements (likert 1-5)
    a. Successful engineers are creative
    b. Successful Army officers are creative
5. Write the first several words that come to mind when you look at the images below (open response)
    a. image source: https://guinnessworldrecords.com/Images/crayon1_tcm25-541020.jpg, accessed 20 AUG 19

    b. image source: https://en.wikipedia.org/wiki/File:No_61_Mark_Rothko.jpg accessed 20 AUG 19

c. Image source: https://en.wikipedia.org/wiki/Pablo_Picasso#/media/File:Pablo_Picasso,_1911,_Still_Life_with_a_Bottle_of_Rum,_oil_on_canvas,_61.3_x_50.5_cm,_Metropolitan_Museum_of_Art,_New_York.jpg accessed 20 AUG 19

Mid-Semester Creativity Exercises Azimuth Check Survey

1. Using the scale below, rate how well you agree with the two statements (Likert 1-5)
    a. The purpose of the "Creativity!" exercises are clear to me
    b. The instructions for each "Creativity" exercise are clearly explained
2. On average, how much time are you spending on each of the out-of-class "Creativity!" exercises? (choose from 5 options)
3. What comments do you have about the "Creativity!" exercises (in-class or out-of-class)? (open response)

End-of-Course Survey (questions related to creativity exercises)

1. Working through the creativity exercises in class and on the problem sets came naturally to me. (likert 1-5)
2. The creativity exercises made me uncomfortable. (likert 1-5)
3. The creativity exercises forced me to think differently. (likert 1-5)
4. I found myself thinking about the creativity exercises in other contexts (courses, clubs, leadership role, etc). (likert 1-5)
5. How would you make the creativity exercises better? (open response)