Creativity is Not a Purple Dragon
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ABSTRACT
There are increasing calls for changes in engineering education to better prepare graduates to be innovative and creative. Yet research on how the creative process can be implemented in engineering courses is scarce. The purpose of this paper and the associated session at the NCIIA conference is to 1) discuss the barriers to integrating the creative process into engineering courses, 2) understand how creativity has been conceptualized in engineering education research, and 3) begin to generate ideas about how elements of the creative process can be implemented throughout the curriculum. The paper reviews engineering education articles from the last five years and discusses how creativity is conceptualized in engineering education research. Results suggest that there is not a clearly defined, well-accepted definition of creativity in engineering education research.

Introduction
During a recent retreat, I (the lead author) had a conversation with a seasoned faculty member who had been teaching engineering for many years. He asked me what types of projects we were currently working on in the Leonhard Center, a teaching and learning and educational research center dedicated to enhancing undergraduate education in the College of Engineering. When I told him that we had recently become interested in the integration of the creative process throughout the engineering curriculum, he exclaimed “I don't buy into any of this creativity stuff.” I was quite surprised by his reaction, and asked him to explain his thoughts. He went on to tell me about a trip to Disney World he had made with his daughter years before. He told me about a movie they watched featuring a cartoon character called “Figment” and said that he did not feel like that sort of thing should be in the curriculum. Figment was a small purple cartoon dragon featured in the “Journey Into Imagination” pavilion at EPCOT. He disguised himself in various ways by pretending to be a cowboy, superhero, dancer, or pirate, and encouraged kids to use their imagination and dream. While Figment may be an appropriate figure for children, this certainly was not the model we had in mind in regard to the engineering curriculum. However, perceptions such as these expressed by the faculty member are a potential barrier and challenge to the kinds of educational innovations that the Leonhard Center wants to achieve in the College of Engineering.

The purpose of this paper and the associated session at the NCIIA conference is to discuss barriers to integrating the creative process into engineering courses, understand how creativity has been conceptualized in engineering education, and begin to generate ideas about how to implement the creative process throughout the curriculum. Specifically, discussion of a systematic creative process, such as that defined by Mumford and colleagues (1991), will be used to frame activities that can be used in engineering courses. We hypothesize that introducing the creative process in this manner will increase the likelihood that instructors will integrate more creative assignments in
Creativity is Not a Purple Dragon
Sarah Zappe, Irene Mena, Thomas Litzinger
Pennsylvania State University
Page 2

Barriers to Integrating the Creative Process in Engineering Education

In the spring of 2012, we invited a faculty member to participate in an upcoming workshop on the creative process being held in the College of Engineering at Penn State. We thought this particular individual would have an interest in the workshop because of a recent meeting we had with him on how he could improve an introductory programming course. During our discussions, he revealed his belief that computer programming was somewhat of an art and that there were various ways to write a program, some of which are more elegant than others. We were disappointed when he wrote to say he would be unable to attend our workshop. During a later conversation, the faculty member said, “The workshop sounded interesting, but I just don’t see how it applies to what I teach.” He may have asked himself “how is creativity important for teaching programming?”

In most universities and colleges, creativity and the creative process are tucked away into various pockets of the engineering curriculum, thought to be the responsibility of those who teach design or perhaps entrepreneurship. Creativity is not typically taught, or perhaps even encouraged, in courses whose objectives are more analytical or technical in nature. However, politicians, engineering educators, and researchers, as well as national organizations, repeatedly speak of the need for our engineering graduates to be more creative and more innovative. The model of the Engineer of 2020 states that engineers should possess practical ingenuity and creativity (National Academy of Engineering 2004). As the Academy states, “Creativity (invention, innovation, thinking outside the box, art) is an indispensable quality for engineering, and given the growing scope of the challenges ahead and the complexity and diversity of the technologies of the 21st century, creativity will grow in importance” (National Academy of Engineering 2004, 55). Several universities and colleges have implemented their own models which have similarities to the Engineer of 2020 model. For example, at Penn State, our undergraduates are encouraged to work towards becoming World Class Engineers, whose attributes include being aware of the world, solidly grounded, technically broad, effective in teams, successful as leaders, and innovative.

While these goals are repeatedly emphasized, only a few institutions, such as Olin, have attempted to integrate creativity across the curriculum (Stolk 2009). Few suggestions are provided by the National Academy or the engineering education research literature at large on how to develop more creative engineers. If creativity is so important, why does the curriculum contain so few examples of efforts to improve students’ creativity? Why do we see examples like the faculty member who felt that creativity had no place in computer programming? Why do we see faculty with a knee-jerk reaction that they do not “buy into” including creativity in the curriculum?

While not conducted in the field of engineering education, a study by Plucker, Beghetto, and Dow (2004) should be considered when pondering these questions. The authors questioned why creativity was not more prevalent in edu-
Creativity is Not a Purple Dragon
Sarah Zappe, Irene Mena, Thomas Litzinger
Pennsylvania State University

Page 3

Educational psychology research and why little is known about strategies for enhancing creativity in the classroom. As they state, “...faculty prior conceptions about creativity creates an atmosphere that severely restricts researchers' and practitioners' ability and desire to study and apply creativity” (Plucker, Beghetto, and Dow 2004). They go on to list four commonly held “myths” associated with creativity, which are summarized below:

1. People are born creative or uncreative, with no capacity for enhancement.
2. Creativity is intertwined with negative aspects of psychology and society, such as drug use, deviance, and nonconformity.
3. Creativity is a fuzzy, soft construct.
4. Brainstorming as a group results in the most creative ideas.

One might wonder how many of these misconceptions about creativity could be held by engineering faculty. Certainly the senior faculty member who associated creativity with “Figment the Dragon” may believe that this “fuzzy, soft” construct is not serious enough to integrate into his engineering courses. Others may not necessarily agree with these myths, but still not understand how creativity fits into the curriculum...or how to enhance it in their students.

In their study, Kazerounian and Foley (2007) pose this critical question: “If creativity is so central to engineering, why is it not an obvious part of the engineering curriculum at every university?” (761). The authors delved into the history of engineering education and hypothesize that, “[c]reativity is not valued in contemporary engineering education” (762). They argue that even capstone design courses have limited emphasis on the creative process and are “mostly limited to ‘synthesis’ exercises using known methodologies” (762). The authors collected survey data from both students and faculty at the University of Connecticut and found that 1) engineering students do not feel that instructors value creativity, and 2) engineering instructors report valuing creativity, but do not see creativity in their students. Engineering faculty were also not found to create classroom environments that were conducive to creative behaviors in their students.

While instructors may report valuing creativity, perhaps they do not know how to create instructional activities that elicit creative responses, or how to motivate and encourage their students to be creative. Kazerounian and Foley provide a list of “Ten Maxims of Creativity in Education”:

1. Keep an open mind
2. Ambiguity is good
3. Iterative process that includes idea incubation
4. Reward for creativity
5. Lead by example
6. Learning to fail
7. Encouraging risk
8. Search for multiple answers
9. Internal motivation
10. Ownership of learning

How many engineering courses contain these elements? While Kazerounian and Foley do not specifically address that issue, consider the typical non-design class in the engineering curriculum. The typical reward structure in these classes emphasizes one final correct answer. Most assignments contain little ambiguity. Students are overly focused on grades and competition. Students are generally not given time for discovery. Professors lead the class by going over practiced and rehearsed problems, with no demonstration of failure.

Stolk (2009) felt that the culture of instruction in engineering education was at fault when considering why creativity is not emphasized. As the author states, one barrier is the “traditional thinking about course design and student-faculty interactions that pervades technical programs...Instructors routinely embrace teaching tactics that outline what exactly students need to learn, how exactly students need to learn it, when the learning must start and end, and why students should care about it” (Stolk 2009). Few opportunities are given to students to discover, explore, and innovate. Another potential barrier, as described by Heywood (2005), is that even if instructors wanted to emphasize creativity more in their classes, they may not know how to assess whether or not student work could be considered creative. They often resort to assessments that rely on having one correct answer, thus communicating to students that creativity is not valued in the course. The difficulty with assessment of creativity is likely a strong barrier that may discourage instructors from integrating assignments that require more creative solutions from their students. Another possible reason concerns the nature of the education that instructors may have received. Instructors often teach in the same manner in which they were taught, which feels familiar and comfortable.

In summary, the following are some of the potential reasons why creativity and the creative process are not well integrated into the engineering curriculum:

1. Myths relating to the nature of creativity as a construct.
2. Lack of ambiguity and opportunities for failure in courses.
3. Rewards structure in most courses.
4. Difficulty assessing creative behaviors.
5. Students’ perceptions regarding instructors’ value of creative behavior.

Participants in our NCIIA session will have the opportunity to generate other possible barriers for the integration of the creative process across the engineering curriculum.

Conceptualization of Creativity in Engineering Education Research

Plucker, Beghetto, and Dow (2004) discussed one additional reason why creativity has not been well studied in educational psychology. The authors argued that a clear and agreed upon definition of creativity is necessary in order to move research forward and to guide practitioners. As they noted, “Without an agreed-on definition of the construct, creativity's potential contributions to psychology and education will remain limited” (Plucker, Beghetto,
Plucker and his colleagues conducted a content analysis of articles relating to creativity in psychology, business, and education. They discovered that the majority of the articles they reviewed did not explicitly define creativity, leaving the reader to interpret their research using their own preconceived definition of creativity. Across the 38% of the articles that contained explicit definitions of creativity, the definitions varied substantially. The authors argue that researchers need to explicitly define creativity in their research and propose an overarching definition based on recent research:

Creativity is the interaction between aptitude, process, and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context (Plucker, Beghetto, and Dow 2004, 90).

The interactionist model of creativity stems from research in industrial/organizational psychology. Creative behavior is viewed as a “complex person-situation interaction” (Woodman and Schoenfeldt 1990, 84) including characteristics of the individual and characteristics of a situation.

After reading the Plucker et al. article, we became curious about how creativity was conceptualized in engineering education and whether a common definition existed. To examine this question, we reviewed journal articles in engineering education from 2006-2011. We examined the following journals: Journal of Engineering Education, Advances in Engineering Education, International Journal of Engineering Education, European Journal of Engineering Education, and Australasian Journal of Engineering Education.

Articles with the words “creative” or “creativity” in the title were flagged for review. We also considered using articles with the word “innovative” and “innovation” in the title. However, it soon became clear that those articles tended to refer more to educational innovations than issues relating to creativity in engineers or engineering students. For example, the Journal of Engineering Education had published an article in 2006 entitled “A Systems Model of Innovation Processes in University STEM Education” (Porter et al. 2006). This article focused on innovations in engineering education, rather than on creativity or the creative process. Therefore, we decided to focus only on articles with “creative” or “creativity” in the title. Additionally, we included only peer-reviewed articles in the analysis, leaving out editorials. Table 1 illustrates the number of articles that were flagged from each journal.

<table>
<thead>
<tr>
<th>Journal</th>
<th>Number of Articles</th>
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<tbody>
<tr>
<td>Advances in Engineering Education</td>
<td>0</td>
</tr>
<tr>
<td>Australasian Journal of Engineering Education</td>
<td>0</td>
</tr>
<tr>
<td>European Journal of Engineering Education</td>
<td>4</td>
</tr>
<tr>
<td>International Journal of engineering Education</td>
<td>10</td>
</tr>
<tr>
<td>Journal of Engineering Education</td>
<td>2</td>
</tr>
</tbody>
</table>

*Table 1. Number of articles identified in engineering education journals from 2006-2011*

Appendix A provides a breakdown of the articles and the themes that emerged in each. First, articles were coded to determine if they contained an explicit definition of creativity. Next, the article was coded to determine if the author
characterized creativity using the following scheme: problem solving, process, product, unique, useful, spiritual, divergent thinking, or interactionist.

Of the 16 articles, nine had explicit definitions of creativity. The nature of these explicit definitions varied tremendously across the papers. An overarching theme in both implicit and explicit definitions of creativity concerned the notion that creativity involved solving problems and finding solutions. Problem-solving was associated with creativity in all of the articles, both in implicit and explicit definitions. Only three articles contained a complete definition of creativity relating to the interactionist model of creativity, which was extremely well described and utilized in the research of Charyton and Merrill (2009).

Several articles relied on dated research on creativity, rather than more recent conceptualizations of the construct. Other common themes included creativity as unique, useful, and involving the creation of a product. There were several instances where creativity was associated with spirituality or mysticism, such as in the article by Silva, Henriques, and Carvalho (2004).

In summary, the review found the following:

1. The number of peer-reviewed journal articles on creativity in primary engineering education journals is very small.
2. There is no consistent definition of creativity used in engineering education research.
3. Researchers primarily consider creativity in relation to problem-solving.
4. Some research understands conceptions of creativity as being of a spiritual nature, which would not be welcomed by many engineering educators.

Current Efforts at Penn State University to Integrate the Creative Process into Courses

The Leonhard Center for the Enhancement of Engineering Education is an endowed teaching and learning and educational research center dedicated to enhancing undergraduate education in the College of Engineering. A primary goal of the Leonhard Center is to implement and support curricular changes that enhance undergraduate engineering students’ development of World Class Engineer attributes. Over the past two years, the Leonhard Center has begun investigating how the creative process could be integrated into the engineering curriculum. In the summers of 2011 and 2012, the Leonhard Center sponsored two workshops for faculty called "Integrating the Creative Process into Engineering Courses." The workshop was co-facilitated by Sam Hunter, an industrial/organizational psychologist and assistant professor at Penn State who specializes in creativity research. One of the goals was to spark ideas on how to integrate the creative process across the engineering curriculum, rather than just in design courses. Appendix B provides an overview and agenda for the workshop.

We considered the 2011 workshop to be a pilot, as we only invited faculty who we felt were most interested in creativity and were also most likely to provide useful suggestions on how to improve the workshop for the future (Zappe, Litzinger, and Hunter 2012). While the assessment data for the 2011 work-
Creativity is Not a Purple Dragon
Sarah Zappe, Irene Mena, Thomas Litzinger
Pennsylvania State University

Page 7

shop was overwhelmingly positive, we questioned whether the success of the workshop would be replicated with faculty who were not the “lead users” in creativity and innovation in the college. In 2012, we invited faculty members who primarily taught non-design, technical, and analytical courses in various engineering departments. Once again, faculty provided us with positive feedback on the workshop. Some said that they would consider approaching the Leonhard Center for funding to implement changes in their courses. The following are example quotes from faculty from the 2012 workshop:

“We as a group tend to value creativity but not reward it in class.”

“Creative process = Engineering.”

“Creativity could be incorporated more broadly into engineering curricula beyond the design-oriented courses.”

One of the reasons for the success of the workshop is the focus on the creative process as defined by Mumford and colleagues (1991), rather than on “creativity.” Figure 1 illustrates the eight stages in Mumford’s model, which begins with problem definition and ends with implementation and monitoring. The model is attractive to some faculty because of the parallels to the design process. They see the creative process as a more structured and understandable approach, as opposed to the “fuzzy” or “spiritual” construct of creativity.

Figure 1. Eight stages in the Creative Process Model according to Mumford et al.

Another reason for the workshop’s success was that we provided time for the faculty members to work on their courses. Participants were encouraged to generate ideas on how they could use the creative process (or portions of the creative process) in their courses. Many felt that they would not be able to incorporate all the steps of the creative process due to time constraints, but felt that they could incorporate activities that involved one or two stages of the process, such as defining the problem or idea generation.

Although Zappe et al. (2012) details some of the examples that faculty generated during the 2011 workshop, the hope is that NCIIA participants will generate additional examples and strategies for integrating the creative process across the curriculum.

Conclusions

In regard to engineering education research, creativity has not been systematically investigated in engineering education. There are few published articles that have tackled creativity or the creative process in engineering education journals. With the exception of a few articles (e.g., Charyton and Merrill 2009) in the journals we examined, modern research in creativity has generally not been integrated into the engineering education literature. There is no widely accepted definition of creativity in engineering education, although the focus has primarily been on problem solving and product creation. Engineering education researchers and journals need to use a clearer, explicit, and agreed-upon definition of creativity.

One limitation of our study is that we did not examine conference papers, such as those presented at the annual meeting of the American Society of En-
Creativity is Not a Purple Dragon
Sarah Zappe, Irene Mena, Thomas Litzinger
Pennsylvania State University

Page 8

A second limitation concerning the review is that it only focuses on the primary journals of engineering education. It does not include design journals or those housed within specific engineering disciplines such as the Journal of Mechanical Design. However, our purposes were to gauge the number and type of articles that appear in the primary engineering education journals. We are aware that engineering design journals will likely have additional work on creativity and engineering design. Given our goal of integrating the creative process across the engineering curriculum, we did not include design-focused engineering journals. Future research studies may expand the set of journals reviewed.

In conclusion, the integration of the creative process across the engineering curriculum may be met with several barriers, including possible misconceptions about creativity and the characteristics of many courses in terms of structure, rewards, and expectations. One possible way to surpass these barriers is to focus on the use of the creative process, rather than on popular conceptions of creativity. Instructors may be more apt to incorporate parts of the creative process when presented in a systematic method, such as the model developed by Mumford et al. (1991). In addition, instructors may want to consider how course instructional techniques and assessment methods should be used to enhance creative behaviors in their students, such as providing opportunities and rewarding for creativity.

References


Creativity is Not a Purple Dragon
Sarah Zappe, Irene Mena, Thomas Litzinger
Pennsylvania State University


Creativity is Not a Purple Dragon
Sarah Zappe, Irene Mena, Thomas Litzinger
Pennsylvania State University
Page 10


### Appendix A: Implicit and Explicit Definitions of Creativity in Recent Engineering Education Journals

<table>
<thead>
<tr>
<th>Source</th>
<th>Explicit definition</th>
<th>Interactionist</th>
<th>Problem Solving</th>
<th>Process</th>
<th>Unique</th>
<th>Useful</th>
<th>Spiritual</th>
<th>Divergent Thinking</th>
<th>Example Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Badran (2007)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>&quot;Creativity can be expressed as the ability to make something new, whether a thought or idea, an object, a product or a process, a work of art or performance, or an interpretation&quot; (Morrison and Johnston 2006) (574).</td>
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<tr>
<td>Bremer, Gonzalez, and Mercado (2010)</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td>&quot;Expose students to the innovation and inventive culture through the definition of challenging problems, which will demand higher commitment and creativity in order to find solutions...&quot; (431).</td>
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<tr>
<td>Byrne and Hansen (2009)</td>
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<td>X</td>
<td>X</td>
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<td></td>
<td>&quot;In this paper, creativity is defined as the unlimited application of knowledge in thinking and doing&quot; (236).</td>
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<tr>
<td>Charyton and Merrill (2009)</td>
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<td>X</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>&quot;[P]ersonal attributes of the individual...influence one's creative process. The environment of the individual, defined as the engineering classroom or industrial setting, also influences the creative process&quot; (157).</td>
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<tr>
<td>Charyton, Jagacinski, Merrill, Clifton, and DeDios (2011)</td>
<td>X</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>&quot;[E]ngineering creativity is defined by a level of novelty or originality (new ideas) and usefulness (practicality)...&quot; (779).</td>
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<tr>
<td>Chen and Hsu (2006)</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>&quot;Four major aspects of studying creativity can be found in the literature: (i) the creative process; (ii) the creative person; (iii) the creative product; and (iv) the creative situation&quot; (264).</td>
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<tr>
<td>Christy and Lima (2007)</td>
<td>X</td>
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<td>X</td>
<td>&quot;Curiosita: an insatiable curious approach to life and an unrelenting quest for continuous learning...Connessione: a recognition and appreciation for the interconnectedness of all things and phenomena&quot; (640).</td>
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<tr>
<td>de Vere, Melles, and Kapoor (2010)</td>
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<td>X</td>
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<td>&quot;Cropley and Cropley (2000) define 'creative' engineers as those who are driven to seek uniqueness, have unusual ideas, tolerate the unconventional and seek unexpected implications&quot; (28).</td>
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<tr>
<td>Hey, Linsey, Agogino, and Wood (2008)</td>
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<td>X</td>
<td>&quot;Analogies to nature or existing problems...often assist engineers in finding innovative solutions&quot; (283).</td>
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<tr>
<td>Ledn-Rovira, Heredia-Escorza, and Lozano Del Rio (2008)</td>
<td>X</td>
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<td></td>
<td>&quot;C)reativity is the ability to use knowledge to solve problems and produce novel works valued by society&quot; (1054).</td>
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<tr>
<td>Authors/Reference (Year)</td>
<td>X</td>
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<tr>
<td>Ogot and Okudan (2006a); Ogot and Okudan (2006b)</td>
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<td>Shoop and Ressler (2011)</td>
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<tr>
<td>Silva, Henriques, and Carvalho (2004)</td>
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<tr>
<td>Takai (2011)</td>
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</table>

*Systematic creativity methods such as the theory of inventive problem solving (TRIZ), guide the concept generation process using solution patterns derived from problems similar to the one at hand* (2006a, 109).

*“...[S]tudents must have... the creativity to envision new solutions to the world's problems”* (1072).

*“To be creative in an engineering context is to use knowledge of numbers, hardware, and technology to create effective and practicable engineering solutions that work better...”* (69).

*“The teacher only has to free the students’ spirit and let creativity fly...”* (70).

*[The Creative Product Semantic Scale] consists of three scales that represent conceptual dimensions: “Novelty, Resolution, and Elaboration and Synthesis”* (380).

*[Creativity] is a social-cultural concept, influenced by factors from an organizational environment in a given cultural context* (1524).
Appendix B: Topics and Agenda for Creativity Workshop

The purpose of the workshop is to generate ideas for integrating creativity into teaching and learning of engineering. A major portion of the workshop will consist of lecture and discussion on the current understanding of creativity. Topics for this portion of the workshop include:

- What is creativity?
- What are barriers to creativity?
- What is the “creative process?”
- What are the antecedents and requirements for creativity?
- What is known about enhancing creativity in others, i.e., our students?
- How can creativity be assessed?

The sessions on creativity will be followed by an opportunity to begin to practice what we have learned. Participants will be broken into teams and challenged to generate ideas on creative activities for teaching engineering topics across the engineering curriculum.

Day 1

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
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</thead>
<tbody>
<tr>
<td>9:00 – 9:15</td>
<td>Introductions, overview of workshop</td>
</tr>
<tr>
<td>9:15 – 9:45</td>
<td>Discussion of pre-work: What is creativity? Where is creativity required in engineering?</td>
</tr>
<tr>
<td>9:45 – 11:00</td>
<td>Background: Importance of creativity, barriers to studying creativity, process models for creativity</td>
</tr>
<tr>
<td>11:00 – 12:00</td>
<td>Antecedents and requirements for Individual Creativity</td>
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<tr>
<td>12:00 - 12:45</td>
<td>Lunch</td>
</tr>
<tr>
<td>12:45 - 2:00</td>
<td>Antecedents and requirements for Team Creativity</td>
</tr>
<tr>
<td>2:00 – 3:15</td>
<td>Antecedents and requirements for Organizational Creativity</td>
</tr>
<tr>
<td>3:15 – 3:30</td>
<td>Wrap-up and Homework</td>
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</tbody>
</table>

Day 2

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
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<tbody>
<tr>
<td>9:00 – 11:00</td>
<td>Enhancing Creativity in Others: Teaching and Leading for Creativity</td>
</tr>
<tr>
<td>11:00 – 12:00</td>
<td>Assessing Creativity: Methods and Challenges</td>
</tr>
<tr>
<td>12:00 to 1:00</td>
<td>Lunch</td>
</tr>
<tr>
<td>1:00 to 2:30</td>
<td>Integrating the Creative Process in Engineering Courses</td>
</tr>
<tr>
<td>2:30-3:00</td>
<td>Planning for next stage of effort: Proposals to design, implement, and assess new activities for engineering classes</td>
</tr>
<tr>
<td>3:00-3:30</td>
<td>Wrap-up and assessment</td>
</tr>
</tbody>
</table>

1. Because of the similarity in the definitions of creativity provided by Ogot and Okudan in these two articles, they are included together in the table.