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Increasing Integration of the Creative Process across Engineering Curricula*

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An interactive workshop has been developed that is intended to increase the integration of the creative process across engineering curricula. The workshop introduces participants to key findings from the research on creativity and the creative process including effectiveness of instruction on creative performance and assessment of creativity. A key goal of the workshop is helping instructors to see the strong parallels between the creative process and the processes used to address novel, complex problems in engineering design, analysis, and experimentation. The outcomes of the first two workshops were quite positive and indicate that it is effective in increasing knowledge about the creative process and in helping engineering instructors begin to design activities for integrating the creative process, or elements of it, into their courses. However, the outcomes also point to opportunities to improve future versions of the workshop.

Keywords: creativity; creative process; design; analysis; laboratory

1. Introduction

In *Educating Engineers for the 21st Century*, the Royal Academy of Engineering notes that one of the key roles for engineers is that of "change agent providing creativity, innovation and leadership necessary to meet new challenges" [1]. In the *Engineer of 2020*, the National Academy of Engineers of the U.S. writes "creativity . . . is an indispensable quality for engineering, and given the growing scope of the challenges ahead . . . , creativity will grow in importance" [2] Unfortunately, in many engineering programs, the teaching and application of a creative process is confined to design courses. Because design courses constitute such a small portion of many engineering programs [3], engineering students may have only one or two opportunities to engage in a creative process during their undergraduate careers. Findings from a study of creativity in higher education are consistent with the restriction of creativity to design courses; the study found that only 13% of engineering students reported that expressing creativity was typically required in their courses [4, 5]. Integrating the creative process into other types of engineering courses would provide students additional opportunities to develop the key skills and abilities required to complete a creative process successfully.

In order to promote integration of the creative process across all types of engineering courses, we have developed a workshop to introduce engineering instructors to the creative process and to enable them to design approaches to integrate the creative process into their courses. This paper begins with a discussion of the creative process model that is the basis for the workshops. The structure of the workshop and outcomes from the first two offerings of the workshop are described. Two possible enhancements to the workshop are then discussed - inclusion of direct mapping of engineering processes to the creative process and a model for integrating the creative process along with the associated challenges faced by instructors.

2. Creative process model

Our work is built upon a model of the creative process based on the work of Mumford, Medeiros, and Partlow [6]. In 1991, Mumford, Mobley, Reiter-Palmon, Uhlman, and Doares published a new model for the creative process [7]. Critical assertions underlying their model are that "creativity begins with problem solving" and that "creativity requires the production of novel, socially-valued products" (p.94). In the context of creativity, the word "problem" should be interpreted very broadly to mean any task that an individual, team, or organization wishes to accomplish [8]. A key characteristic of the creative problem solving process is that the problems must be ill-defined and novel; otherwise, routine problem solving based on past experience and existing knowledge will suffice. For engineers, problems that demand creative solutions can occur in design as well as analysis and experimental work.

In their recent paper, Mumford, Medieros, and Partlow [6] reviewed research work during the 20 year period following the publication of the first version of Mumford's creative process model [7]. They discuss three critical propositions that underlie their creative process model: (1) creative problem

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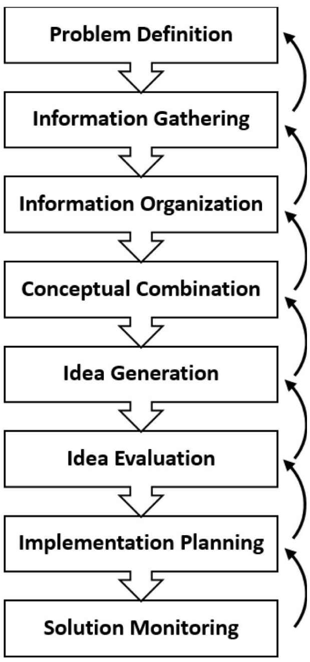

Fig. 1. Creative Process from Mumford, Medeiros and Partlow [6].

solving is based on knowledge and information, (2) existing knowledge must be recombined and reorganized to generate novel ideas leading to problem solutions, and (3) ideas must be "evaluated and shaped into viable plans for directing work on a creative product." A graphical representation of their most recent creative process model is presented in Fig. 1; the curved arrows indicate that it is often necessary to return to earlier phases of the process. Mumford, Medeiros, and Partlow [6, p. 31] describe this model as follows: "This model assumes that creative thinking begins with problem definition. Problem definitions, in turn, lead to information gathering and selection of the concepts used to understand this information. These concepts then provide a basis for conceptual combination. The new knowledge emerging from conceptual combination, in turn, allows for idea generation and evaluation of ideas. Following selection of viable ideas, implementation planning begins with people actively monitoring the outcomes of their actions as they implement their plans. These processes are held to operate in a dynamic fashion, with failure in executing any one process leading people to cycle back to early processing activities."

3. Description of workshop

The first workshop was offered in May 2011, and the second was offered in May 2012. The workshops were each two days in duration. Participants were compensated for participation with two days of salary because the workshops were held after the end of the normal academic calendar. Both workshops were led by one of the authors whose research focuses on creativity and innovation in business and industry.

Prior to attending the workshop, participants were asked to define creativity, in their own words without using references, and to list as many ways in which engineering involves creativity as they could. During the first hour of the workshop, the participants were provided with lists of the definitions of creativity and also the ways in which engineering involves creativity. They were asked to find common elements in the definitions to draw out key aspects of creativity. They were then asked to group the statements on creativity in engineering into common categories. The goal of this activity was to encourage deep processing of the lists and to begin to broaden participants' thinking about how the creative process can be incorporated into the education of engineering students.

Following this activity, the participants were introduced to the creative process model presented in Fig. 1 as well as creativity in individuals, teams, and organizations. The discussion of creativity focused on knowledge, skills, and abilities that support creative performance [9]. As part of the team creativity discussion, participants were put into small groups and asked to build a tower using spaghetti, marshmallows, string, and tape. As a homework assignment at the end of the first day of the workshop, participants were asked to read a paper on barriers to integrating the creative process into engineering courses [10].

The second day of the workshop focused on teaching and leading for creativity as well as assessment of creativity. A key reference for the discussion of teaching for creativity was a quantitative review of the effectiveness of creativity training [11]. The final activity of the workshop was developing ideas for integrating the creative process, or elements of it, into engineering courses. The participants shared their ideas with the group. An agenda and more details on the workshop can be found in [12].

4. Outcomes from the workshops

The May 2011 workshop had nine participants. Most of the participants had experience teaching design or entrepreneurship courses. The group quickly and easily engaged the process of developing activities to integrate the creative process into their courses. Among the activities that they created were in-class exercises to help students practice problem identification and information gathering, and monitoring—phases of the creative process that are not often included in typical course assignments

[12]. In the problem identification activity, students are shown a photograph of a real situation, e.g., a jammed downtown street in India, and are asked to identify problems that might have engineering solutions. The information gathering activity involved providing students with a broad statement of a complex, novel situation based on a real-world problem and then requiring students to ask questions to more clearly define the problem.

A post-workshop survey was completed by eight of nine participants. One of the survey questions asked what was most useful about the workshop. One participant noted that the most useful thing learned was "Learning about the 8-stage model and seeing how similar it is to design process!" Another noted that "There can be ways to add small amounts of creativity . . . work into a class . . . Just need to be creative." Another question on the survey asked participants if they felt that the workshop would be successful with a broader sample of engineering faculty members who do not teach design or entrepreneurship. All respondents answered yes to this question, but they did offer some caveats, e.g., (a broader sample of faculty would) need to have an open view of creativity.

The second offering of the workshop in May 2012 was directed at such a broader group of instructors who teach engineering analysis courses such as statics, dynamics, and thermodynamics. There were eight participants. During the afternoon of the second day, the participants were asked to come up with activities that would require students to engage in all or part of the creative process. Many of the ideas of the group focused on bringing novel, complex problems into the course so that students would be required to engage more phases of the creative process:

- Having students undertake analysis of an ill-defined structure such as a "marshmallow/spaghetti tower" or a real-world structure that they chose. This type of challenge would require students to undertake nearly the entire creative process: from problem definition, information gathering, generation of different approaches for analysis, selection of one method, planning and execution of that method.
- Bringing research problems into a class on polymers to challenge students to improve their ability to define and formulate problems.
- Integrating more "real-world" problems into their teaching and assignments. Asking students to solve real-world problems would engage them in problem definition and information gathering, stages of the creative process not required by problems that typically have appeared in undergraduate textbooks
- Present a design challenge to students that require them to make a choice supported by analysis, but restrict them to analysis that can be done without computers.

One participant offered an idea that involved teaching the creative process explicitly in a sophomore course and then asking students to engage in the process. After students learned about the creative process, they would be challenged to design and solve problems that utilize key concepts and methods from the course. To encourage students to be creative in their work, this participant suggested providing more credit when their problems were "far from the examples in the textbook." This approach asks students to exercise nearly the complete creative process, including the problem identification stage.

Results from a post-workshop survey of participants were positive. One participant stated that the most useful part of the workshop was, "Learning more about the creative process and how creativity might be incorporated more into the courses I teach." Other comments regarding the most useful aspects of the workshop follow:

- "I liked the discussion of different ways to apply creative approaches in engineering."
- "Ideas of how to directly apply creative techniques in my classroom from in-class activities to exam questions to problem solving sessions."
- "Ability to put the creative process into words."
- "Understanding creativity as a process and learning what the process is."
- "The exposure to a formalized creative process."

A general theme in the survey responses is that the creative process needs to be incorporated more into teaching engineering, as reflected in the following quotes:

- "Since the creative process is important in engineering, we should try to incorporate it in teaching our courses."
- "We as a group tend to value creativity, but not reward it in class."
- "Creativity should be incorporated more broadly into engineering curricula beyond the design-oriented courses."
- "Creative process = Engineering."

Suggestions for improving the workshop included having more concrete examples, having more group activities during the actual workshop, and having different and more interesting physical space. One participant stated, "I would have liked more concrete ideas or conclusions about the challenges brought by incorporating creativity in classroom teaching. Another individual stated that he or she would like "more examples of in-class activities that

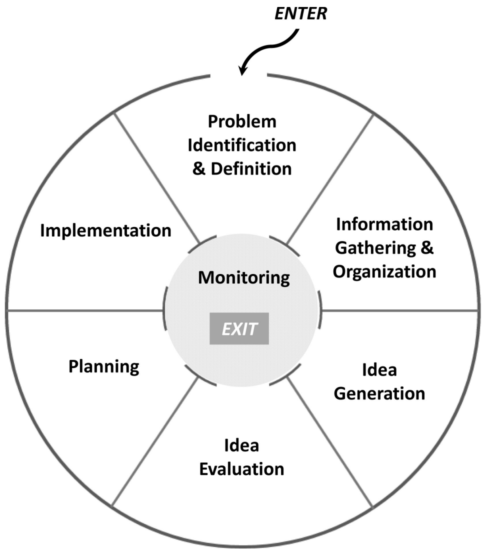

Fig. 2. Creative Process Model derived from [6].

others have used that are more detailed.'' Another stated, ''more activities, more brainstorming sessions geared at generating specific examples that can be implemented in engineering.'' Two participants mentioned that they would like a larger workshop size, although one acknowledged that ''the small group dynamic was effective.''

5. Discussion

Although participants seemed to understand the importance of the creative process in engineering, many requested more concrete examples of how the process could be applied in their courses. One mechanism to provide more concrete examples is to explicitly draw parallels between the creative process and complex problem solving in engineering. Demonstrating parallels between the creative process and the methodologies used to address complex problems in design, analysis and experimentation will allow instructors to more easily envision how they can adapt their courses to explicitly include discussion and use of the creative process. In order to do this, we have developed a modified version of the creative process model of Mumford, Medeiros, and Partlow (Fig. 1) that more closely aligns with design and problem solving processes in engineering. We have also developed a series of tables comparing this creative process model to methods used to address novel, complex problems in engineering design, analysis, and experimentation. In addition, we feel that future workshops could be improved by providing participants with an explicit model for implementing the creative process into a course and the challenges that it brings. The last portion of this discussion section describes the model that we have developed based on prior research.

The graphical representation of the modified version of the creative process model is presented in Fig. 2; it includes separate planning and implementation phases. We have included ''problem identification'' [13] explicitly in the first phase to emphasize its importance. Following the representation of the problem solving process used by Woods [14], we represent the creative process by a set of rooms arranged in sectors around a central hub to emphasize the interconnected nature of each of the phases. Monitoring serves as the hub to indicate that it should occur throughout all phases. Indeed, it is monitoring that drives the problem solver to ''cycle back'' to earlier phases of the process to refine the output from that phase. The Exit is shown in the hub as well to indicate that it is possible to exit the creative process at any stage, but that an exit should occur only after monitoring. Descriptions of each of the phases are presented in Table 1.

Table 1. Description of the phases of the Creative Process Model

Phase	Description
Problem identification and definition	Identify and define problem. Problem definition should include desired outcomes as well as known constraints.
Information gathering and organization	Search broadly for information relevant to the problem and organize it for use in later phases. Output of this phase provides input for the generation of alternative solutions. It may also lead to more detailed descriptions of outcomes and constraints.
Idea generation	Generate options for addressing the problem. (This phase encompasses concept selection and combination from Fig. 1)
Idea evaluation	Select best options for addressing the problem by evaluating against outcomes and constraints. (Evaluation may include creation and testing of prototypes.)
Planning	Create detailed plan to fully implement the selected 'solution.' (Creating the implementation plan may require working through a separate creative process depending on the complexity of the solution.)
Implementation	Execute plan.
Monitoring	Monitoring must occur throughout the phases and at the end of each phase. It is likely that monitoring will lead to a decision to cycle back to an earlier phase to refine the output of that phase.

Successfully solving a novel, complex problem in design, analysis or experimentation requires execution of a process with strong parallels to the creative process in Fig. 2. That such parallels exist is not surprising when one considers the fact that the model of the creative process on which Fig. 2 is based grew out of the literature on complex problem solving [6].

Table 2 compares the creative process to the product development process described in Ulrich and Eppinger [15]. (An in-depth discussion of the literature on design and creativity is available in a paper by Howard, Culley, and Dekoninck [16].) It is rare for students to engage in the full product development process defined by Ulrich and Eppinger; more likely they will only complete a prototype of their selected concept. For a design course in which students produce a prototype, their experience would map to the creative process as illustrated in Table 3. Thus, design projects afford students the opportunity to engage in many of the phases of the creative process. The one step that the students seem least likely to engage is problem identification.

However, it is possible to engage students in the process of identifying and defining opportunities so that they can practice and develop this skill. Some participants in the first workshop noted that students often lack an opportunity to practice these important skills; as a result, the participants designed new course elements aimed at this phase of the creative process [12].

Table 4 compares the complex problem solving process proposed by Woods [14] to the modified creative process of Fig. 2. Based on an extensive review of the literature, Woods proposed a general process for problem solving in an academic context. He defines problem solving as requiring the solver to "create a plan" as opposed to being able to apply an approach used to address similar problems in the past. Thus, Woods' problem solving process is one used to address problems that are novel or unfamiliar to the solver. Although he does not explicitly use the terms in his definition of problem solving, he notes that others have applied the terms "atypical" and "ill-structured" to such a problem solving process. Woods' six step process is as follows: define the stated problem, explore, plan, do it, look back, and transition. Transition is used to describe monitoring that should occur between each of the stages. His process assumes that the problem is presented to students and therefore does not include "identify the problem."

As an example of how the creative process can be integrated into a class that is focused on theory and analysis, we consider mechanics of materials. To begin, students are asked to identify real-world problems that they will analyze using the theory and analysis methods of the course. Such an assignment could ask students to walk about their campus and photograph interesting structures, or students could use the internet to search for interesting structures. Engaging such real-world problems

Table 2. Comparison of Creative Process to Product Development Process [15]

Creative Process	Product Development Process
Problem identification & definition	Identify opportunities and prioritize; create mission statement.
Information gathering and organization	Identify customer needs; set target specifications. Search internally and externally; explore systematically.
Idea generation	Generate concepts.
Idea evaluation	Evaluate in order to select optimal concept; this phase may include design, fabrication and testing of prototypes.
Planning	Set final specifications; complete system level and detail design; plan manufacturing process.
Implementation	Implement plan for production.
Monitoring	Ulrich and Eppinger include reflection steps within many of the major phases of the overall process.

Table 3. Comparison of Creative Process to Process for Developing Product Prototype

Creative Process	Process for Developing Product Prototype
Problem identification & definition	Create mission statement (often completed by the instructor).
Information gathering and organization	Identify customer needs; set target specifications. Search internally and externally; explore systematically.
Idea generation	Generate concepts.
Idea evaluation	Evaluate in order to select optimal concept.
Planning	Complete design of prototype and create plan for fabrication.
Implementation	Implement plan for fabrication of prototype.
Monitoring	Reflect upon quality of work in each phase of process and on the overall process.

Table 4. Comparison of Creative Process to Problem Solving Process [14]

Creative Process	Process for Solving Novel Problems
Problem identification & definition	Define the problem: identify goals, constraints and criteria, both stated and inferred.
Information gathering and organization.	Explore: identify key content knowledge, estimate values for answers; create an internal. image of the problem; write clear goal statement; identify constraints.
Idea generation	Explore: Estimate a result; consider different sets of simplifying assumptions and the resulting solutions; consider possible ways to decompose into simpler sub-problems.
Idea evaluation	Select best approach.
Planning	Plan.
Implementation	Do it.
Monitoring	Reflect between stages (transition) and after completing the solution (look back).

will require students to gather information about the structure they have chosen, to consider various levels of approximations, and different methods of analysis to determine forces, stresses and strains. If the students have skills with solid modeling and stress analysis, they could compare results from simplified analysis using traditional analysis methods to results from a computer-based simulation. They could be asked to discuss the pros and cons of the two methods as part of the monitoring process. Thus, beginning with the selection of real-world problems by the students affords opportunities to engage in most of the creative process.

Inquiry-based approaches can be used to introduce the creative process into laboratory courses. Minner, Levy and Century [17] provide a descriptive model of inquiry-based science, which is mapped to the creative process in Table 5. Key elements of inquiry-based learning include: posing questions, examining information to understand what is already known, planning and conducting investigations, analyzing data, and evaluating explanations/predictions [18]. A growing number of examples of inquiry-based laboratories can be found in the engineering literature. A few examples are: Flora and Cooper [19] who explored the use of student designed experiments in an undergraduate laboratory in environmental engineering, Liang and Camesano who developed a series of inquiry-based laboratories to introduce second-year students to nano-technology [20], and Kypuros, Vasquez, Tarawneh, Wrinkle, and Knecht who implemented a series of guided discovery modules involving hands-on activities to support student learning in statics and dynamics [21]. Of these three examples, Flora and Cooper's implementation of inquiry-based laboratories provides the most extensive integration of the creative process because they allowed their students to select the topics to be investigated. After selecting their topics, the students designed and conducted experiments, and analyzed the results.

Successful implementation of the creative process into engineering courses requires attention to people, problems and climate as represented in Fig. 3. The people involved are the students, the instructor and teaching assistants. Their knowledge, skills and attitudes play critical roles in carrying out the creative process. The instructor, and to a lesser extent the teaching assistants, must have appropriate pedagogical knowledge as well as technical knowledge. They must understand the challenges of implementing the creative process successfully.

Among the challenges are that some of the students will be uncomfortable with the unstructured nature of the creative process. Others may not think of themselves as creative and may be intimidated when asked to engage in a creative process. It is, therefore, very important for the instructor to communicate to the students that the focus is on the creative process, not creativity alone, and that the

Table 5. Comparison of Creative Process to Inquiry-based Experimentation [17]

Creative Process	Inquiry-based Experimentation
Problem identification & definition	Generate questions to be answered and/or predictions to be tested.
Information gathering and organization	Gather information and use prior knowledge to refine questions and to support design of experiment.
Idea generation	Create multiple options for experimental investigation.
Idea evaluation	Evaluate merits of different designs including whether they are feasible.
Planning	Create experimental procedure.
Implementation	Implement experiment; analyze results; adjust/refine procedure as needed.
Monitoring	Discuss research questions based on previous study or data collected; consider where and how issues of bias may need to be addressed; ensure conclusions are supported by data.

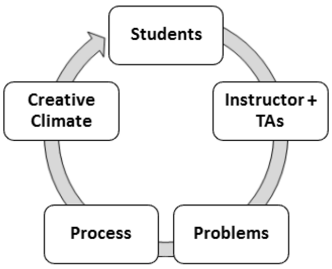

Fig. 3. Elements required for integration of creative process into a course.

goal is to help them develop the ability to engage novel, complex problems. It will also be important to explain to students that creativity is something that we all have, but that we have in varying degrees. Guilford's view of creativity was that those who are viewed as being creative simply have "more of what we all have" (p.446) [22].

Selection of the problem or creative challenge is a critical part of successfully integrating the creative process into a course. The creative challenge must be at a level of sophistication that is proximate to the current knowledge and skill set of the students. If it is too advanced, most students will fail and frustration levels will rise for the students and the instructor. When providing students with opportunities to engage novel complex problems, it is important to explain what is involved and why it is important for students to learn to engage in a process that will involve lots of hard work and at least some level of frustration. This is especially important if challenging students to engage the creative process is not a typical approach to teaching and learning. If it is likely that many students will fail to achieve an appropriate solution, it is very important to make that clear to the students and to reassure them that the process, not the outcome, is the goal of the learning experience.

When students are presented with opportunities to engage the creative process, there must be an appropriate balance between the level of challenge and the level of support that is provided. For example, in inquiry-based laboratories, it may be appropriate to use a guided approach so that students do not find themselves becoming too frustrated for lack of progress. In the guided approach, the instructor monitors progress and intervenes at appropriate points to keep students moving forward at an appropriate pace.

Achieving a proper balance between challenge and support is one of the factors that will affect students' perception of the creative climate in the course. Climate is typically defined by social scientists as the commonly held beliefs and perceptions about environmental attributes shaping expectations about outcomes, contingencies, requirements, and interactions in the work or educational context [23, 24]. Creative climate, then, represents those specific perceptions about support— or lack thereof — for novel and innovative thinking [25, 26].

6. Conclusion

An interactive workshop that is intended to increase the integration of the creative process across engineering curricula has been developed and offered to two groups of engineering instructors. A key component of the workshop is helping instructors to see the strong parallels between the creative process and the processes used to address novel complex problems in engineering design, analysis, and experimentation. The results of the two workshops indicate that it is effective in increasing knowledge about the creative process and in helping engineering instructors begin to design activities for integrating the creative process, or elements of it, into their courses. The workshop will continue to be offered and refined to increase its effectiveness. Two changes planned for future offerings of the workshop are explicitly showing the mapping of the creative process to engineering processes and providing a model for inclusion of the creative process in engineering courses.

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