Incorporating Creativity into a Capstone Engineering Design Course

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Abstract

Creativity is a critical part of engineering design that should be encourage and nurtured in engineering students. Two creative exercises were implemented into a senior chemical engineering design course. The first exercise was designed to enhance student awareness of the role of creativity in engineering design. In this exercise, students were asked to create a piece of artwork depicting their major (chemical engineering) in some way and to reflect on the process they followed to produce their artwork. The second exercise was designed to improve student understanding of process safety and analysis of process hazards through role-playing. Groups of students were given information on a real process where an accident had occurred in order to provide them the technical background on the process. Then, they pretended to be a safety review team looking at the process before the accident occurred to try to predict potential hazards. One team used HAZOP analysis, while the other used the "What-If?" method for evaluating process safety. The activity where students created a piece of artwork and reflected on how the process of creating art related to engineering design was successful in getting students to think about the process of design and how it is similar to a creative endeavor. An activity using role-playing to have students practice performing a hazards analysis of a chemical process appeared to improve student understanding when the students were given enough time and detailed enough instructions on what they were to accomplish in the role-playing.

Introduction

Engineering design is undeniably a creative exercise: the engineer must create something that never has existed before using only the tools of mathematics and science. However, engineering students likely do not see their engineering training as requiring much creativity, particularly in their first few years of college when they take mainly math, science, and engineering science courses. These courses require students to be adept problem solvers, but don't typically ask them to be particularly creative.

Engineering students are expected to be creative in the engineering design courses they take towards the end of their curriculum. However, the transition from mastering the fundamentals of introductory courses to the open-ended world of engineering design can be challenging to students. Students frequently want to fall back on the methods they have used in previous courses, for example looking for "the equation" that will provide a solution. Old ways of solving problems may not lead to sound engineering designs, suggesting that students need to be encouraged to develop new skills when approaching a design problem.

The role of creativity in engineering in general, and in engineering design specifically, has long been recognized and discussed in the literature. Dym et al. recently reviewed the literature on the types of thinking required of students in a design course[1]. These authors described how design is difficult for students to learn and for faculty to teach because it requires both divergent (generating multiple questions and possible solutions) and convergent (trying to find the single best solution) thinking. Eris reported on the types of questions that designers ask during the design process, a reported a mix of what he called generative design questions that led to a wide variety of solutions and questions designed to reveal facts[2]. These articles suggest that design courses should teach students how to be creative in generating different potential solutions.

A number of engineering educators have developed methods for teaching creativity to engineering students. Felder described several activities (open-ended questions, divergent thinking or brainstorming exercises, and problem generation) that he implemented in a junior-level fluid mechanics and heat transfer course and suggested that these activities both provided students with the opportunity to be creative and helped them develop their use of creativity to solve engineering problems[3]. Korgel described the used of journal writing in an engineering laboratory course to promote deeped learning and creativity[4]. Liu and Schonwetter described how they applied a problem solving methodology developed by Treffinger et al.[5] to stimulate and develop creativity in engineering students[6]. With this methodology, the instructor showed the students how to apply three hierarchical levels: learning and using basic thinking tools, learning and practicing a systematic process for problem solving, and working with real problems. The thinking tools described in level one include analogical thinking[7], brainstorming[8], mind mapping[9], and others. Chan et al. describe the InnovTech facility within the City University of Hong Kong that seeks to train creative professional engineers[10]. This facility teaches creative problem solving processes, creative idea generation techniques, and bring industrial problems to the students.

Leon-Rovira et al. and Ogot and Okudan both discussed how to use a systematic creativity method called the Theory of Inventive Problem Solving (TRIZ) in engineering courses[11,12]. TRIZ was developed in 1946 by Genrich Altshuller[13], and has the design team compare their to a large number of design problems in diverse engineering fields and convert their problem into a general TRIZ design problem. They can then access previous solutions for problems of their general type in order to solve the specific design problem. Ogot and Okudan suggested that teaching students the TRIZ method was preferable to teaching only brainstorming methods. Leon-Rovira compared the results on a creativity test of a group of students exposed to TRIZ with one not exposed to it, and found the the group taught the TRIZ method had a higher percentage of students with students in the “Very Creative” or “Above average” categories.

The literature review suggests that creativity can be taught, and that engineering education can be enhanced by inclusion of activities whose objectives is to foster student creativity. This article reports on two exercises used in a senior chemical engineering design course to enhance student awareness of the role of creativity in engineering design and to involve a creative exercise to enhance learning of process safety. In the first exercise, students are asked to create a piece of artwork depicting their major (chemical engineering) in some way. They are further asked to reflect on the process they followed to produce their artwork. In the second exercise, students are given information on an industrial process and asked to role-play a team of engineers evaluating the process hazards associated with this process. This paper describes the implementation of these exercises, the desired outcomes, and the qualitative results obtained through use of these exercises.

Procedures

Two activities were incorporated into ChE 570 Chemical System Design I, a required senior-level capstone design course at Kansas State University. The first activity required students to produce a piece of art depicting chemical engineering, and required them to reflect on the process they used to create this piece of art. This activity was used in the fall semesters in 2007, 2008, and 2009, and was assigned the first week in the course. The second activity, a role-playing exercise providing students with the opportunity to practice two common safety review techniques, was used in fall, 2008 and fall, 2009 and was assigned at the end of the course when the class was discussing process safety.

The artwork project provided students with the opportunity to reflect on the process of creating something, and to think about the role of creativity in engineering design. Students were asked to individually create a piece of artwork and answer several questions about their process for creating the piece of art. The text used to describe the assignment is shown below.

Your assignment is to create an original piece of artwork that depicts the body of knowledge in chemical engineering. This artwork can be made in any media that you choose (painting, sculpture, etc.). While you are making your masterpiece and after you have completed it, reflect and write about the following questions:

1. *Describe what your piece of artwork means. How does it depict chemical engineering?*
2. *How did you come up with the original idea for the artwork? Did you consider multiple ideas initially or just one? How did you choose between your multiple ideas?*
3. *What steps did you follow to create your piece of art? Did you complete it in one sitting or were multiple attempts made?*
4. *How did you know when you were finished with your artwork?*
5. *In what way does this exercise relate to designing a chemical process? How can you use your experiences making your piece of artwork in this course?*

The role-playing exercise asked students to assume the role of a team assigned with the task of evaluating the process hazards associated with a chemical plant. Students were presented information on a real chemical plant that had experienced a severe accident in the past. This information was obtained from the United States Chemical Safety Board website which provides the results from numerous accident investigations[14]. A critical aspect of this information is that the plant in question had serious design flaws that led to the accident. This means that the students can role-play how one might find these design flaws using established safety review techniques. Students are provided all the information about what happened and why, so they already know what the problems with the process are prior to the role-playing exercise. This is desirable because it is doubtful that the students have the necessary experience to find the design flaw that caused the accident.

Students in the class were split into two groups. One group applied HAZOP (hazards and operations) analysis to evaluate the potential safety issues associated with an ethylene oxide sterilization facility. The other group used "WhatIf" analysis to evaluate the safety hazards associated with an acetylene manufacturing facility. Each group was provided with a list of roles on the team that had to be filled. This included the character name, profession of the character (team leader, process engineer, operations supervisor, etc.) and a few character traits. The character traits were chosen to add levity to the role playing, for example one character frequently mentioned his or her beloved cat while another was deathly afraid of spiders.

Each group was given a class period to select which group members were going to play which roles (not all students got to participate in the role-play), what types of "What If?" questions or HAZOP keywords they are going to use, and how to organize their "performance". During the next class meeting, each group presented their analysis of the safety hazards associated with their assigned process in front of the class. Following the presentation, the audience was asked to discuss how the group had used "What If" or HAZOP analysis and to hypothesize what the cause of the eventual accident was.

Results

Creative Project Assignment

Students used a wide variety of different media to represent chemical engineering, producing hand-drawn pictures, collages, songs, poems, dioramas, painted pictures, and sculptures. The open-ended nature of the assignment meant that no two projects looked alike. Not only did students choose different media for their project, but they also had widely varying interpretations of how to represent chemical engineering. Many focused on applications of chemical engineering or piece of equipment that chemical engineers work with. Some used symbols from companies who hire chemical engineering in their artwork. Others focused on their own experiences in chemical engineering, depicting the material they had learned in their courses in some way. Some students used very tangible objects or pictures to represent chemical engineering, while other's artwork was abstract.

Student response to this project revealed several things. First, students greatly enjoyed the opportunity to do something different in an engineering class. Many students had creative interests and abilities that they had not gotten much of a chance to use in their engineering curriculum, and they enjoyed the chance to use those abilities. For example, one student (who had been a music teacher in a prior career) composed a piece of music for the piano that represented his progression through the chemical engineering coursework. Other students reported that they had little artistic talent, yet even these indicated that they had enjoyed the assignment.

The text describing the process for making the artwork was more important than the artwork itself. The questions the students were asked to answer were designed to encourage metacognition of the creative process. Generally, students provided written evidence that they recognized the key steps in the creative process (i.e. idea generation, decision of which option to pursue, implementation of idea, review of success of process and possible reworking) and could link engineering design with creativity. Most students indicated that they had multiple ideas for their artwork, sometimes only in their head and sometimes ones that they had sketched out or written down. Some students also indicated that they needed several iterations to complete their artwork. Most students recognized that engineering design is also a creative process, and many of the steps they followed to make their art project would need to be followed when designing a chemical process. For example, many noted that multiple alternative would need to be explored and that the process may need to be examine several times to find the best solution, much as they made changes to their art project. They also indicated the need to define the scope of the problem for both their artwork and in a design project.

The only negative to this project was that some students appeared to spend little time on the project. Because they were graded not on the artwork itself, but on their reflection on the creation process, this did not necessarily mean a lower graded. The small amount of time spent on the project could give the wrong impression about the process of creation: the design process necessitates iteration, much as creation of fine art should as well.

Role-Playing Exercise

The role playing exercise had mixed results in the two years it was used, mostly because of poor implementation in the first year. In the first year, students had less than one hour of class time to prepare for the in-class role-playing. The resulting product was of low quality: the skit did not go into much depth on the use of the “What If” and HAZOP techniques, which was the goal of the exercise. The students were expected to prepare outside of class, and that was clearly a mistake. In addition, clear expectations for the skit were not provided in terms of the number of “What If” questions or HAZOP parameters that should be explored.

The second year was much more successful, mostly because additional time was provided for the students to prepare for the exercise. An equally important part is to provide a thorough explanation of the techniques before announcing the assignment, and providing some clear guidelines on what should be included in the skit. In the second year, the students were told to include at least three “What If” questions and to explore at least two HAZOP parameters along with multiple key words for each parameter. The students were able to meet these guidelines, and were able to demonstrate an understanding of “What If” and HAZOP analysis.

The inclusion of unusual characteristics for each member of the safety evaluation team was done to make the exercise more fun. This was viewed as important since the students had just turned in their design reports detailing the results of their semester-long design project. However, this can backfire, as the groups in the first year spent much of their time trying to be funny and less time actually practicing the important skills.

This activity allowed the students to be creative in how the presented themselves (in character) and how they handled the safety review. They were not told what parts of the process to examine (though the accident reports gave them considerable hints), but were allowed to evaluate the process as they saw fit. It is thought that this flexibility as well as the fact the students themselves were pretending to be part of the safety evaluation made this exercise much more powerful than other ways that hazards analysis could have been presented. For example, in

2007 the students were asked to watch a recorded Powerpoint presentation with audio that described hazards analysis. This was, for most students, a tedious way to try to learn the material, and probably much less effective at teaching the students about analyzing process hazards. It is thought that students achieved a greater understanding of hazards analysis through this exercise, though quantitative data are not available to prove this.

Conclusions

Two exercises were incorporated into a capstone design course in an effort to provide students with the opportunity to be creative and to reflect on the role of creativity in engineering design. An activity where students created a piece of artwork and reflected on how the process of creating art related to engineering design was successful in getting students to think about the process of design and how it is similar to a creative endeavor. An activity using role-playing to have students practice performing a hazards analysis of a chemical process did appear to improve student understanding when the students were given enough time and detailed enough instructions on what they were to accomplish in the role-playing.

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