ON THE IMPORTANCE OF IMBEDDING CREATIVITY IN ENGINEERING EDUCATION AND RELEVANT LESSONS FROM AGILE ORGANIZATIONS' PRINCIPLES

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INTRODUCTION

Engineering courses are generally well-structured in order to provide a proper background knowledge and cover a large number of technical topics over a finite period of time. Students learn the scientific concepts through lectures and problem solving, laboratory experiments and special projects, or a combination of those learning tools. Flipped classes and other student engagement techniques and learning tools stimulate class involvement and enhance students' understanding of the concepts, as meticulously presented in class and textbooks. These are powerful and time-tested methodologies for learning what has been known and discovered in the past.

Design and capstone courses allow students to exercise their creative ability within some defined boundary conditions and also aid the learning process so long as students do not cross the lines as taught through well-accepted methodologies in class or as presented in their textbooks. Those creative ideas generally center around improving some accepted design techniques or processes or in some cases even better scientific and engineering approaches, but still within a defined space.

Given the complexities of some of the engineering concepts, this time-tested approach has been successful in teaching engineering concepts within a structured curriculum. What is lacking, however, is the opportunity for students to think "out-of-the-box" and exercise and unleash their creativity beyond some academically defined boundaries. Yet, the discipline of engineering has often advanced when pioneers dared to think differently and proposed ideas that were contrary to the traditional methodologies and way of doing things.

In their article, entitled: Teaching Creativity in Engineering [1] Liu and Schonwetter conclude that "understanding creativity and the creative process in the context of engineering is essential for an instructor to be able to foster creativity in engineering students." They further refer to the work of DeWulf and Baillie [2] that suggests "creativity potential often lies dormant in most students and it is the instructor's responsibility to unblock the barriers and unlock or ignite creativity". Furthermore, referring to the work of Treffinger, Isaksen, and Dorval,[3] they submit that "teaching with a purpose of facilitating creativity would also help students learn more about their own creative abilities, and attain greater personal and professional success…".

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There is a famous saying, paraphrased: If you always step on others' footprints, you will never leave your own. With that premise the author decided to incorporate a new dimension in his engineering courses, starting fall semester 2021, affording students some latitude to exercise their abilities to think differently without the fear of being outcast. This paper describes the methodology and the preliminary results and outlines certain conditions that would foster the creation of an environment conducive to creative and innovative thinking.

It should be noted that requiring a creative approach in projects through out-of-the-box thinking is vastly different from assigning open-ended projects. As an example, a taxicab company may seek open-ended solutions to improve its mode and efficiency of operations and attract new customers. There may be many different ways to improve such operations and their efficiencies, hence an open-ended problem. An out-of-the-box thinker, on the other hand, would suggest the creation of a ride sharing platform that connects people who need rides to those who wish to earn additional compensation by driving folks to their destinations. The two methods are vastly different. One is based upon the conventional approach to problem solving, and the other is a disruptive new approach that alters the way one views the problem and challenges the conventional assumptions.

CREATIVITY ASSIGNMENT

At the beginning of the semester, the author included short period discussions with students in several class meetings about the importance of creative and "out-of-the-box" thinking. The author provided real examples of industrial and business advancements that have been made when scientists, engineers, and business leaders dared to step out of their comfort zones and unleashed their creativity to bring about new and innovative ideas, simple or complex, that others never took the time to think about or consider. The author and students talked about failure being part-and-parcel of such an endeavor and should not be viewed as a defeat. In fact, failure should be accepted positively, as long as one learns important lessons from it. Again, the author provided real-life examples of initial failures that led to great achievements later on. During these sessions, the group also talked about self-imposing boundary conditions that people often construct in their minds, much of it due to the way science and engineering education structured their thinking, that limit or inhibit deviations from the accepted norms.

Based on those discussions, the author asked the students to submit a creative idea related to the class material at the end of the semester. The author stressed that this assignment would not be graded, hence they did not have to be concerned about the exact correctness or realistic implementation of it, albeit they had to provide a reasonable scientific justification of their proposed ideas. The author made this task a mandatory assignment for the completion of the course with no grades attached to it. The students also had to present their creative ideas to the rest of the class and entertain questions.

On the last day of class, the author asked the class to complete a short Qualtrics® survey to assess the impact of this initiative on their learning outcomes. Only after they had completed their assignments and completed the survey and when the survey was closed, the author announced that he would give the junior-level students a few bonus points for all their efforts on this assignment, all the while knowing that there were no grades associated with it. All junior-level class teams far exceeded the expectations. Hence, bonus points were awarded equally to all teams. No bonus points were awarded to the senior/graduate level (4000/6000 level) class as they were expected to show more effort.

What some teams accomplished truly surprised the author, including printing 3-D versions of their creative ideas and proposing completely different designs and even new and innovative applications of existing technologies. More importantly, there were interesting findings from the survey. The survey questionnaire was made available to three classes, an undergraduate-junior level course with 21 students, an undergraduate-senior level course with six students, and a graduate course with four students. The author taught these courses during the Fall Semester 2021 and the subjects were Transfer Science I (Heat Transfer), Introduction to Rheology, and Advanced Rheology. The questionnaire was designed to receive feedback on how students felt about this creativity exercise and whether or not the experience helped their understanding of the subject. It should be noted that the number of graduate students was not statistically significant, and no major difference was observed in their responses.

RESULTS

All students responded to the survey for a total of 31 responses. The responses were all included in the survey results without distinguishing among the three classes. Table 1 includes the results of the Qualtrics survey, conducted by the Tennessee Tech Center for Innovations in Teaching and Learning.

ANALYSIS OF THE RESULTS

In attempting to evaluate these responses, one should be cognizant of the limited number of data points, a total of 31 students in two undergraduate courses and one graduate course, which limits the degree of comprehensiveness of this study. As such, the results should be viewed as pre-

TABLE 1
Results from the survey assessing the impact of the creative assignment initiative on learning outcomes of participant students. Thirty-one students completed the survey.

Question	Survey Responses										Mean	Standard Deviation	Variance
	1	2	3	4	5	6	7	8	9	10			
1. "How did the exercise of creative and innovative thinking and considering the alternative technological and design possibilities impact and inform your understanding of the subject?" *Rating Score*: 1 = No impact at all; 10 = Most helpful	0	0	0	1	2	5	6	7	6	4	7.61	1.58	2.50
2. "How difficult was it for you to 'step out of the box' and think in ways of nontraditional engineering design and potential applications?" *Rating Score:* 1 = Not difficult at all; 10 = Most stressful	1	0	3	0	6	4	7	5	2	3	6.48	2.15	4.64
3. "How concerned were you about your peers' acceptance or rejection of your creative ideas?" *Rating Score*: 1 = No concerns at all; 10 = Very concerned	9	4	4	1	4	4	1	1	2	1	3.87	2.73	7.47
4. "Do you believe that your proposed idea is realistic and with sufficient additional work can be implemented?" *Rating Score:* 1 = Not realistic; 10 = Absolutely doable	1	0	1	2	4	1	8	6	4	4	7.03	2.16	4.68
5. "Did you consider the economical, and social impact of your proposal, i.e., how others might benefit from the proposed idea in terms of costs and convenience?" *Rating Score:* 1 = Did not consider it at all; 10 = Those factors were most important	1	0	3	4	3	3	4	10	2	1	6.29	2.17	4.72
6. "Were you surprised by your ability to think creatively and propose great ideas?" *Rating Score:* 1 = Did not surprise me at all; 10 = I was very pleasantly surprised	1	2	1	0	8	4	7	2	4	2	6.23	2.24	5.01
7. "Do you think this creativity exercise should be implemented in most engineering courses?" *Rating Score:* 1 = No, not at all; 10 = Yes, absolutely	0	0	0	0	3	4	4	5	4	11	8.16	1.74	3.04
8. "Were you more creative when you worked with your team members as a group to develop new ideas?" *Rating Score:* 1 = Most creative when worked alone; 10 = Most creative when worked with others	3	0	0	1	4	2	5	6	4	6	7.03	2.61	6.81

liminary findings. To better understand what the surveyed students in three different courses have indicated, it might be helpful to review the relevant literature on the subject and draw references from the work of other researchers.

In a previous study by Ghorashi,[4] the author cites the work of Noel, Levitz, and Saluri [5] which indicates that students will be more likely to persist to graduation when the instruction is individualized and cultivates relevant knowledge. Ghorashi,[6] on the topic of student success, also submits that "... different individuals, even within a defined group, may have vastly different needs; hence, customizing the institutions' efforts to the specific needs of each individual student can enhance the retention and graduation rates...".

MASS INDIVIDUALIZATION

Based on the above premise, one could draw a corollary that one way to individualize the instruction is to stimulate individual creativity in class related projects or solution of the assigned homework problems. In that sense, while the lectures, projects, and case studies remain the same for all students, the solutions to problems or projects may differ based on an individual, or if applicable, a team's creativity.

This would be one way to individualize the instruction, particularly in a large class, to the level of each individual student, similar to what is known in the world of business and agile organizations as "mass individualization" or "mass customization." By offering individualized education through stimulation of individual creative solutions to complex engineering problems and design projects, not only will students' creative abilities expand, but research shows [5] that students' persistence to graduation will be enhanced.

The very first question on the survey was "how did the exercise of creative and innovative thinking and considering the alternative technological and design possibilities impact and inform your understanding of the subject?" Clearly a strong majority of the students' responses indicated that indeed, the exercise of creative and innovative thinking informed their understanding of the subject.

RECOGNIZING THE STUMBLING BLOCKS TO CREATIVITY

Liu and Schonwetter,[1] referring to the work of Christiano, and Ramires,[7] submit that "it is the instructor's responsibility to teach students how to recognize and remove blocks to creativity." Some of those blocks to creativity include:[7]

a. Fear of the unknown
b. Fear of failure
c. Reluctance to exert influence
d. Frustration avoidance
e. Resource myopia ("failing to see one's own strengths and depreciating the importance of resources …")
f. Custom-bound ("over-emphasizing traditional approaches or methods…")
g. Reluctance to let go
h. Impoverished emotional life (… "attempting to hold back spontaneous expressions…)

On the question of "how difficult was it for you to 'step out of the box' and think in ways of nontraditional engineering design and potential applications," the majority rated the question above 5, on a scale of 1 to 10, with 10 being most stressful. Items (a) through (h) could be the contributing factors in this case.

When asked, "how concerned were you about your peers' acceptance or rejection of your creative ideas," the majority were not that concerned. This result was very encouraging as it speaks highly of their self-confidence and their ability to be independent thinkers.

The students' high level of self-confidence was also reflected in the way the majority responded to the question that asked if they believed that their proposed idea was realistic and with sufficient additional work can be implemented. The majority felt positively about that and rated the question above a value of 5.

On the question of "Did you consider the economical and social impact of your proposal, i.e., how others might benefit from the proposed idea in terms of costs and convenience," the majority responded that they did consider those factors, with most ratings above 5, on a scale of 1 to 10, with the greatest number of students indicating a rating of 8. This result very positively reflects the view of students about others and their genuine desire, as engineers, to positively contribute and help solve the societal problems.

A slim majority of respondents were surprised by their ability to think creatively and propose great ideas. Perhaps item (e) above, "failing to see one's own strengths," was a contributing factor to this result.

As a student-focused engineering educator, perhaps the most important finding, in view of the author, is the students' response to the question, "do you think this creativity exercise should be implemented in most engineering courses?" The overwhelming majority responded above 5, with the highest number giving the question a rating of 10 on a scale of 1 to 10 with 10 being "yes, absolutely".

On the question of "were you more creative when you worked with your team members as a group to develop new ideas?," the majority felt that they were more creative when they worked as a member of a team, which indicates the importance of teamwork and what has been advocated by many, in the industry and business world, as the tremendous impact of self-directed teams. Potentially, items (c) and (d) above, i.e., "the reluctance to exert influence", and "frustration avoidance," might be the contributing reasons for a response from only a few who rated this question below 5.

In that regard, the importance of team onboarding, i.e., defining teams' responsibilities and a clear set of initial instructions, expectations and accountability, cannot be overstated. If done properly, student teams can become engines that energize and induce the creation of an environment in which creativity would flourish.

LESSONS FROM AGILE ORGANIZATIONS

Agile organizations rely on the knowledge and creativity of their workforce in order to address change and uncertainty. Kidd and Henbury,[8] in a paper on agile manufacturing, define some of the key words linked with the agile paradigm, among them: "Dynamic teaming: actively looking for and building off the creative and innovative talents of other team members. Transformation of knowledge: explicitly transforming raw ideas into a range of capabilities which are then embodied in both products and services."

As mentioned previously, in this study the majority of respondents felt that they were more creative when they worked as a member of a team. To fully exercise their creativity, it is paramount that student teams function as self-directed groups. In that regard, one can find numerous articles and studies in the agile manufacturing and agile organizations literature related to the impact of self-directed teams. In a report by Aghina, De Smet, Lackey, Lurie, and Murarka,[9] the authors submit that "when given clear responsibility and authority, people will be highly engaged, will take care of each other, will figure out ingenious solutions, and will deliver exceptional results."

As related to applicable lessons from agile organizations, Goldman, Nagel, and Preiss [10] state "the behavior of individuals in groups is strongly influenced by their understanding of how their performance is to be measured." This notion reinforces the importance of providing clear instructions to student teams as related to their goals, objectives, and responsibilities as well as the assessment of their performance.

This premise may also hold true for self-directed and academically coached student teams. To encourage creative thinking in teamwork, one has to recognize the importance of proper methods to establish successful teams. Zarske, Yowell, Maierhofer, and Reamon, [11] in a study on teamwork in first-year engineering projects, conclude that early teams dynamic training may result in long-term benefits for team performance even extending to post-collegiate career. Wolfe, Powell, Schlisserman, and Kirshon,[12] in a paper on teamwork in engineering undergraduate classes, recommend that engineering educators consider ways to implement teamwork instruction, interpersonal communication strategies, project management tools, and conflict management strategies into the engineering curriculum. Additionally, Biernacki, [13] in a paper on student teams, submits that by empowering teams with an "Agreement of Responsibility" that spells out the commitment of each team member and the consequences for non-compliance, student teams can become self-governing.

Team formation and proper teamwork training, as well as the inclusion of a creativity assignment as a mandatory part of the completion of a project, allow students to express a diversity of ideas and opinions to their fellow team members. As a result, diversity, equity, and inclusion will make each team stronger by enabling the team to consider a wider array of possibilities as individual team members express their perspectives in an open environment of dialogue. Students are reminded to value each idea, freely discuss and debate their viewpoints, and after careful consideration achieve a consensus representing the team's view as a whole. This approach provides each team member an equal ownership in the final product and encourages students with different viewpoints to express their thoughts. It affords the team to establish a broader base for innovative solutions beyond the traditional modes of the past. Much research work is being conducted in the area of diversity, equity, and inclusion tools for teamwork [14] due to its importance and impact.

CONCLUSIONS

The majority of students surveyed gave a rating of greater than 5 (on the basis of 1 to 10) to the question of "how difficult was it for you to 'step out of the box' and think in ways of non-traditional engineering design." As such, it was not an easy task for them to leave an otherwise comfortable space that they were familiar with and think differently. However, the majority were not concerned about their peers' acceptance or rejection of their creative ideas, indicating a high level of self-confidence in their ability to be independent thinkers.

Similarly, their high level of self-confidence was reflected in the way the majority responded to the question that asked if they believed their proposed idea was realistic and with sufficient additional work could be implemented. The majority felt positively about the potential practical applications of their creative ideas and rated the question above a value of 5.

Another encouraging response was the students' attention to the economical and social impact of their proposals and how others might benefit from their proposed idea in terms of costs and convenience. The majority did consider those factors, with the greatest number of students giving a high rating of 8 to that question. This result shows the students' genuine desire, as engineers, to positively contribute and help solve the societal problems.

Additionally, a slim majority of respondents indicated that they were surprised by their ability to think creatively and propose great ideas. This seemingly hidden talent can be cultivated in an environment conducive to creative thinking and will inevitably flourish.

The most important finding of this study was the students' response to the question "do you think this creativity exercise should be implemented in most engineering courses?" By far, the majority responded with a rating with the highest number, giving the question a rating of 10. Also, the majority felt that they were more creative when they worked as a member of a team.

In addition to the survey results, previous studies by other investigators stress the impact of self-directed teams and team onboarding, i.e., defining teams' responsibilities and providing a clear set of initial instructions with expectations and a mechanism for accountability. If done properly, collaborative teams can become engines that energize and induce the creation of an environment in which innovation would flourish.

Similar to the mass customization concept in the world of business, the author introduces the term "Mass Individualization," as relevant to the academic world, and provides a premise that creativity assignments, particularly in a large class, offer the benefit of individualizing the instructions and hence fostering student success and progression. It is noteworthy and most gratifying to deduce from the results of this study the students' desire to solve, on a technical level, the societal problems, which is a hallmark of good engineers.

RECOMMENDATIONS FOR FUTURE WORK

As noted earlier, the results of this study are based on the data from only two undergraduate courses and one graduate course. As such, the above results should be viewed as promising, yet preliminary. Hence, further work on a larger scale is needed which might include a more exhaustive set of questions to properly analyze the results. Moreover, the survey should include questions pertaining to details and nuances that might reveal additional information that otherwise may not be deduced from a limited set of data.

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