Creative Engineering for 2020

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ABSTRACT

The United States National Academy of Engineering's seminal work, *The Engineer of 2020 – Visions of Engineering in the New Century*, was written to prepare industrial, governmental, and academic institutions for the future of engineering. The authors of the report state, "Emphasis on the creative process will allow more effective leadership in the development and application of next-generation technologies to problems of the future." In 2011, 2012, and 2013, engineering undergraduates from the Valparaiso University College of Engineering (Valparaiso, Indiana, USA) participated in a four-day off-site course focused on creativity, innovation, teamwork, and leading the creative process. The course was taught by members of the engineering faculty and included sessions and on-location tours (near Orlando, Florida) that were led by instructors from an external training organization. Pre- and post-course surveys identify a significant improvement in the students' understanding of the roles of creativity, innovation, and the roles of leadership, communication, and teamwork in the creative process.

Keywords: Engineering, Creativity, Innovation, Leadership, Soft-Skills

1. INTRODUCTION

In late 2001, the National Academy of Engineering established a steering committee to envision the state of engineering in 2020 [1]. The intent behind the project was to develop a framework for the future of undergraduate engineering education in the United States. At the completion of their work, the committee concluded that specific predictions of the future would be difficult; therefore, multiple scenarios were considered. Each scenario reflected various developments and breakthroughs in technology (including nanotechnology, biotechnology, and computing). *The Engineer of 2020 – Visions of Engineering in the New Century* was published to present the Academy's aspirations describing the attributes required for engineering in 2020.

As expected, strong analytical skills and the ability to work under increasing economic, legal, and political constraints were highlighted. However, the text is overwhelmingly dedicated to identifying a number of "soft skills" as essential attributes of the 2020 engineer: practical ingenuity, creativity, communication, business management, and leadership [1].

Of these soft skills, engineering students are often most challenged to develop and hone their creativity. For engineers, creativity may be defined as developing novel and original ideas with emphasis on their applicability to solving problems [2, 3]. This definition of creativity is more specific for engineering students than for students in other majors (i.e. art, music, creative writing, theater, etc.) For engineers to exercise creativity within their discipline, a need exists for utility within the constraints of the physical world [4]. Aesthetics are secondary to solving problems or forestalling future problems [3].

Teaching engineering students a disciplined approach to the creative process, however, has eluded academia [5]. While students and professors alike have increased interest in creativity, engineering curricula are still overwhelmingly focused on mathematics, sciences, and engineering fundamentals [6]. Therefore, a need exists for instructing engineering students in the creative process that complements existing engineering, math, and science classes.

Along those same lines, one widespread misconception is that engineers and engineering students do not necessarily need to have good presentation, multimedia, and communication skills [7, 8]. This misconception is fueled by the assumption that the engineers will do the design and development work, while the salespeople will present and sell the product. The reality is that engineers with below average communication skills are at a disadvantage because they will have a hard time communicating their ideas to their peers and presenting their work to their superiors. As a result, the Accreditation Board of Engineering and Technology (ABET) requires students to develop both oral and written presentation skills [9]. Moreover, our institutional Student Learning Objectives explicitly state that, "Students will communicate clearly and effectively in both oral and written forms" [10].

In this paper, we describe a new class dedicated to inspiring the creativity, communication, and leadership skills of undergraduate engineers in an innovative, outside-the-box approach. The rest of the paper is

organized as follows. Section 2 describes the overall concept, intent, and expected outcomes for the class. Section 3 includes logistical information detailing the class organization and costs. Section 4 describes the course content and implementation. Section 5 details the assessment of the class. Finally, section 6 contains the conclusions of the paper.

2. AN ENGINEERING CREATIVITY CLASS

To address the development of its undergraduate engineering students' soft skills, Valparaiso University's College of Engineering began in 2001 to incorporate lessons encouraging their development in its senior design class [11]. Specific lessons on creativity were embedded into additional classes in the following years [12]. However, engineering students have been found to be better prepared for solving engineering problems by introducing concepts like creativity outside of traditional classrooms [13]. Therefore, teaching engineering students the creative process should be performed in an immersive environment with student-centered, experiential activities [14]. Such environments allow professors to act more as facilitators and allow students to take greater responsibility for their own education and increase the levels of interactive education and peer-to-peer learning [14].

After reviewing the National Academy of Engineering's *The Engineer of 2020*, the Creative Engineering course was conceived in April, 2011. The course would introduce engineering students to the creative process and challenge students to define and explore the topic of creativity in engineering. The objectives for the class are shown in Table 1.

TABLE 1: Objectives for Creative Engineering Class

1.	Students will be able to give examples of creativity in engineering.
2.	Students will be able to use tools and processes that help them to be more creative.
3.	Students will be able to explain how individuals can be more creative.
4.	Students will be able to explain the role of a leader in the creative process.

Students participating in the Creative Engineering course were asked if they were creative and to assess their abilities to meet the four objectives in Table 1 using a Likert scale (1 being "No, Not At All" and 5 being "Yes, Definitely"). Because the students in the class self-selected to enroll, a control group of undergraduate engineering students was given the same survey to see if the class participants showed any inclination prior to the trip that may have differed from their peers. The outcomes of the survey are shown in Figure 1. From the responses, it appears the average of the self-selected course participants is comparable to the control group.

Valparaiso University decided to partner with an external training organization to develop the Creative Engineering class for three reasons. First, it would allow professors to serve as facilitators and guides for the class. Second, working with an external training organization would help reduce the faculty load required for developing and implementing the course. Finally, partnering with an internationally recognized creative organization would make the course a hands-on, real-life experience and bring a certain amount of prestige to it [15, 16].

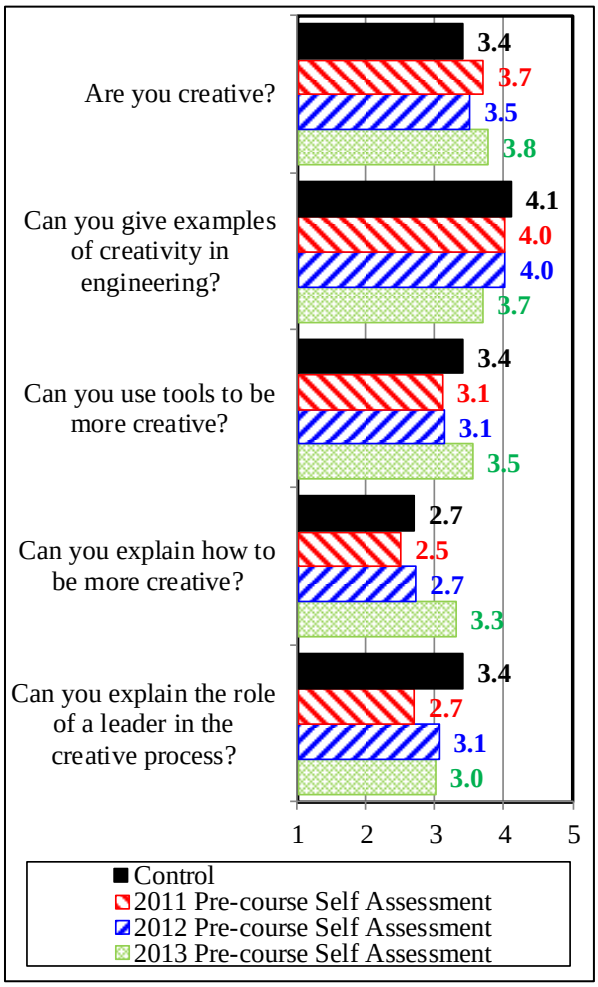

FIGURE 1. Averages of student self-assessments performed before the 2011, 2012, and 2013 Creative Engineering course using a Likert scale (1 being "No, Not At All" and 5 being "Yes, Definitely"). Data is also provided for a control group of students that did not participate in the class.

3. COURSE LOGISTICS

In the Creative Engineering course, a team-teaching approach was used. The course was facilitated by Valparaiso University College of Engineering faculty, while specific on-location classes, tours, and workshops were be led by instructors from the external training organization. In addition, faculty served administrative roles in course development and implementation, handling all the logistics related to traveling to and from the external training organization's location in Lake Buena Vista, Florida, near Orlando.

A significant amount of discussion was undertaken to decide if the course should be offered for credit or non-credit. Upon recommendation by the Dean of the Valparaiso University College of Engineering, the decision was made to offer the course for one credit, for three reasons. First, students would be participating in approximately twenty hours of lecture and laboratory activities. Second, the students' participation and classwork would be reflected on their transcripts. Finally, offering the course for credit would allow the faculty to have some leverage to dictate appropriate student behavior in the course.

Because of the opportunity to hold on-location classes, tours, and workshops at the external training organization headquarters in Florida, a significant amount of logistics was required. To facilitate students' class and extracurricular schedules and minimize travel costs, the class would meet at the external training organization's site during the Valparaiso University Fall Break (in October). Since this allowed only four days and nights to conduct the course, we decided to fly the participants from Chicago to Orlando. To simplify travel plans and ensure the on-time arrival and departure of the students, we decided to organize all travel plans through the Valparaiso University College of Engineering. Students were housed in hotels (double-occupancy) owned by the external training organization to facilitate easy access to their on-site facilities. The external training organization also provided all of the transportation required in the Orlando area.

Table 2 shows the costs of the trip for the past three years. The cost for the initial trip (in 2011) was significantly higher for three reasons. First, a hotel in the external training partner's "moderate" classification was chosen in 2011. In future years, the course used housing in the "value" classification. Second, a significantly longer and more expensive on-site tour (8 hours) was used in 2011. The tour included a meal and trips to four of the external training organization's theme parks, necessitating the rental of a tour bus for the day. The courses in 2012 and 2013 opted to have shorter (5 hour and 4 hour, respectively) tours that only visited the on-stage and back-stage areas of one theme park. Finally, the 2011 trip included a significantly more expensive workshop on creativity than the courses in 2012 and 2013. The $586 cost of the 2011 class was paid for by a grant from the Valparaiso University's College of Engineering Dean's Fund, reducing the actual student cost to $1,087 - nearly identical to the 2012 and 2013 courses. Scholarships and additional financial assistance have also been made available to at-need students through the Dean's Annual Fund.

TABLE 2: Costs (Per Student) for the Creative Engineering Course, 2011-2013

Trip Component	Costs		
	2011	2012	2013
Airplane tickets	$ 323	$ 288	$ 311
Hotel rooms	$ 245	$ 183	$ 191
On-site tours	$ 223	$ 59	$ 34
Venues, food, and beverage	$ 100	$ 224	$ 276
External organization classes, workshops	$ 586	$ 60	$ 57
Theme park tickets for class activities	$ 145	$ 158	$ 162
Team shirts	$ 36	$ 56	$ 57
Supplies	$ 14	$ 62	$ 5
Total	$ 1,673	$ 1,091	$ 1,094

In 2011, 22 students participated in the Creative Engineering course. This number increased to 28 students in 2012. In 2013, however, the external training organization requested that the number of students be capped at 16. This was in part due to several new classes and workshops that were being offered in 2013 for the first time.

4. COURSE CONTENTS

The contents of the course can be categorized as three short courses, three off-stage tours, and three guided discussions, and engineering scavenger hunts.

A. SHORT CLASSES

During the trip, students had the chance to attend a total of three short courses offered by the external training organization's theme park staff members. The classes covered the following topics:

Creativity: In this short class, the instructors started by giving a short presentation on ways to think outside the box to come up with creative ideas. The presentation also included techniques and strategies for an effective session of brainstorming.

The instructors then divided students into four groups of four. They gave the different groups the assignment of coming up with a project/idea that will improve their College of Engineering. The students were also given time and budgetary restrictions. At the end of the exercise, each group had to delegate a representative to pitch their project in less than 60 seconds. The whole class then discussed the project and brainstormed to refine the projects and make them more feasible.

Leadership: In the leadership short class, the instructors started by defining leadership and its impact on individuals and their surrounding communities. They also categorized leaders into four different classes and gave examples of each class. For example, Mark Zuckerberg is an entrepreneurial leader because of his ability to take an idea and make a realistic profitable enterprise out of it. Walt Disney, on the other hand, is a visionary leader because of his ability to think and envision things others cannot even imagine. Servant leaders are people who are elevated to the leader status because of their dedication and the level of services they provide. Finally, opportunity leaders are people who seize an opportunity and unexpectedly step up to fill a void in situations where leadership is needed. Good examples of those leaders are politicians who lead their countries in times of distress or military officers who lead their armies in battles and wars.

At the end of the presentation, students were asked to identify the type of leadership that best fits their personalities and think of a situation where they can be effective leaders. A moderated discussion also took place of the skills and the talents that a leader needs to exhibit in order to be effective in his role. This module culminated by an exercise where the instructors shared 8 quotes with the names of 8 leaders and asked the students to match each quote to who they thought said it. The exercise helped highlighting the differences between leaders and their various leadership styles.

Teamwork: This short class consisted of two separate modules. In the first module, the class met in the open air in a street of one of the theme parks featuring various state-of-the-art animation movies. In that street, the instructors talked about the movies and discussed the various steps associated with the creation of such a product. These steps include, but are not limited to: story writing, character creation, music, scripts, scenarios, and drawings.

Students were then given the assignment of creating their own animation movie. They had to designate different tasks to different team members or committees. They also had to assign coordinators to ensure that an adequate amount of communication is taking place between the different committees. Students found out that leadership and communication were key to achieve any substantial progress.

In the second module, the class met in a food court in an indoor setting. In this meeting, students were split into four teams of four and were given the task of creating a marketing plan for a restaurant.

Before getting their assignment, the instructors asked each team to choose a team leader. The instructors then went against the teams' choices and selected another individual to be the leader. The real-life lesson is that you will not always receive the leader you want. Yet, the team should still move on and do their best to achieve their goals regardless of who their leader is. Moreover, halfway through the completion of the marketing plans, the instructors picked the individual who was the most productive in each team (not necessarily the leader) and asked them to switch teams. This was heart breaking for most of the teams. The real-life lesson from this exercise was two-fold: for the switched individual, they had to realize that although they were doing great work and they had a great plan with their old team, they have to move on and adapt to their new team and help them implement their new team's plan. For the rest of the team, the lesson is that it is common for the superstars in a team to be recruited and lured away to another job; it is the responsibility of the remaining team members to stay composed, and train the replacement to blend in and become productive.

B. OFF-STAGE TOURS

Theme park staff members from the external training organization led the group in three off-stage tours where the students had the chance to observe the daily operation and functions that take place behind the scenes. The three tours took place in the following locations:

Costume & Cosmetology Department: In this department, students observed the different stages of creating costumes for the various characters in the theme park. Students found out that the costume creation is not that different from the engineering design process they are learning in their curricula. It starts with the management or customer specifying a statement of purpose with a set of constraints and criteria. The designers meet and brainstorm to come up with one or more ideas to take to the design phase. In this phase, various coworkers create various hand

drawn designs and/or computer aided designs to facilitate the production phase. In production, different entities are given different assignments ranging from fabric selection, to cutting, sewing, and assembling the final product. The last step would be testing and verifying that the product is satisfactory to the customers' needs.

Animatronics: In this tour, staff members explained how the theme park develops and incorporates animatronics in their various rides and attractions. They also explained that the incorporation of mechatronics in a way that seem animate rather than robotic is only possible by the creativity of a team of brilliant engineers. Those engineers understand, because of their technical background, the limitations and the possibilities of the technologies in use. There was a near consensus at the end of this tour that animatronics is the ultimate exhibition of creativity in engineering and was a perfect marriage between the art and technology.

Roller Coaster: This tour, led by engineers from the theme park, had a technical nature. Students from all engineering disciplines enjoyed learning details about the construction, electrical, and mechanical aspects of the roller coaster. The engineers graciously offered to answer questions from the students afterward.

C. GUIDED DISCUSSIONS

Guided discussions are class activities that were carried out independent of any theme park staff members. The instructor asked the students to attend certain events or ride certain attractions and followed that by discussions of what was observed. The following three guided discussions took place in the class.

Software Design: For this discussion, the whole group enjoyed riding one of the theme park attractions. Following the ride, the instructor led a discussion of ways to keep the ride interesting for frequent riders. For those people, the ride may become too predictable and loose its thrilling effect and its attractiveness. The group discussed that periodically re-designing the hardware of the ride will be, not only very expensive, but also will result in frequent down times of the ride. The alternative is to allow the software to infuse some randomness in the ride by randomly modifying its trajectory. The instructor noted how the parameters cannot be totally random but pseudo random to keep the ride within the safety levels and maintain its entertainment value. This resulted in a follow up discussion about the importance of maintaining good public relations and the damage that would be caused by rides' down times or risky malfunctions.

Communication Skills: For this activity, students attended multiple presentations with reference to different countries in the world expo at the theme park. Following the presentations, students were asked to compare the different presentations. Students observed that one presentation focused on the cultural aspect in the country while another was centered on the scenic and beautiful nature and the third emphasized the famous music of that country. The real life lesson that the students learned is that a presenter will be often given a short time to make a pitch or present their case. A smart presenter should be able to efficiently use the short time put their best features in the spotlight and find a way to highlight their strong suits and make a lasting impression on the audience. To follow up on this activity, students were asked to individually present themselves to another engineer in 30 seconds.

The Museum: The museum documents the beginnings of the different theme parks from the concepts to the ground breaking all the way to the opening and the consequent developments and additions. The museum also contains a nice archive of the characters in the theme parks and their chronological developments. The students were particularly interested in seeing the timeline of the development of the audio-visual technologies used in the parks and in the creation of the animated movies.

The museum dedicates a big section to the founder of the theme parks. The section shows a model of his office and videos of his presentations and speeches in a way that highlights his brilliance as a visionary leader. It also highlights his go getter attitude and his entrepreneurial mindset. The class enjoyed touring the museum and discussing what was seen in it.

D. ENGINEERING SCAVENGER HUNTS

The students self-selected into smaller teams (2-3 students) and participated in engineering scavenger hunt at several of the external training organization's theme parks. This activity was organized by the Valparaiso University College of Engineering faculty. Students were no longer responsible for exploring the theme park as they might have before this course; instead, they looked at attractions, shows, restaurants, and facilities and observed the engineering challenges and opportunities in each one [15]. Additionally, some of the items were intended to challenge the students to become more creative themselves. Some examples of the scavenger hunt's challenges were:

- If you are able, go on [specific attraction]. How realistic was the ride? Could it be more realistic?
- Which attraction in the theme parks has the highest theoretical hourly ride capacity (THRC)? Estimate its THRC and explain how you calculated it.
- Go see [specific show]. How could it be done differently if a complete redesign was started today?

- Go on [specific attraction]. Are the robotic animals and characters very life-like? How would the attraction change if they were more life-like?
- Go see [specific attraction]. Is immersion the future of entertainment? Why or why not?
- Go see one of the 360° movies. How would you design the theater so guests do not have to stand?
- The budget for [specific attraction] was over $100,000,000. Estimate a budget for the 10 most expensive items in the attraction.
- Engineers have to be open-minded. Try a food that you have never had before. Extra points will be awarded if you try sushi.

After designated periods of time on the scavenger hunts, the students and faculty met for review sessions to see how the students were doing. The faculty acted now as facilitators, allowing the students to lead the discussion and ask and answer each other's questions.

5. COURSE ASSESSMENT

There are many ways to evaluate creativity including interviews, observations, and self-assessments. However, there is evidence that self-efficacy is a reliable predictor for topics like creativity where confidence levels impact a student's performance [17]. Therefore, after the Creative Engineering course, students again were asked to self-assess if they were creative and their ability to meet the four objectives in Table 1, using the same Likert scale. The results are shown in Figure 2. Also included is the improvement seen in the student self-assessment averages following the course. The data is also summarized in Table 3. (Note that the data for the Control Group and the 2011 course were calculated to two significant digits. This was changed to three significant digits in 2012 and 2013).

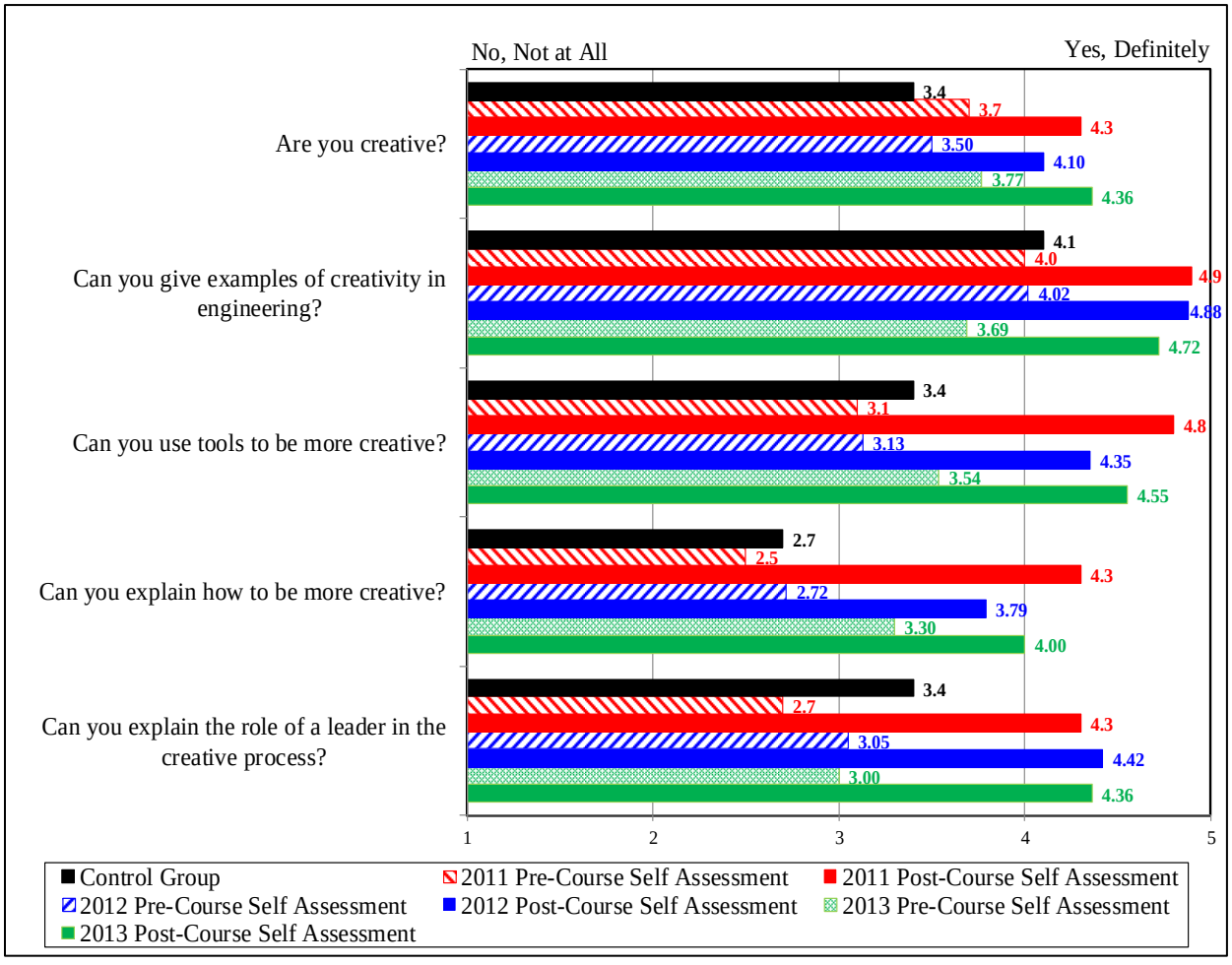

FIGURE 2. Averages of student self-assessments performed before and after the 2011, 2012, and 2013 Creative Engineering course using a Likert scale (1 being "No, Not At All" and 5 being "Yes, Definitely"). Data is also provided for a control group of students that did not participate in the class.

TABLE 3: Averages of students' self-assessments performed before and after the 2011, 2012, and 2013 Creative Engineering course using a Likert scale (1 being "No, Not At All" and 5 being "Yes, Definitely"). Also shown is the delta (improvement) in the self-assessments after the class.

Self Assessment Questions	Control Group	2011			2012			2013		
		Pre-Course	Post-Course	Delta	Pre-Course	Post-Course	Delta	Pre-Course	Post-Course	Delta
Are you creative?	3.4	3.7	4.3	+0.6	3.50	4.1	+0.60	3.77	4.36	+0.59
Can you give examples of creativity in engineering?	4.1	4.0	4.9	+0.9	4.02	4.88	+0.86	3.69	4.72	+1.03
Can you use tools to be more creative?	3.4	3.1	4.8	+1.7	3.13	4.35	+1.22	3.54	4.55	+1.01
Can you explain how to be more creative?	2.7	2.5	4.3	+1.8	2.72	3.79	+1.07	3.3	4.00	+0.70
Can you explain the role of a leader in the creative process?	3.4	2.7	4.3	+1.6	3.05	4.42	+1.37	3	4.36	+1.36

Are you creative? After each Creative Engineering course, students reported approximately a +0.60 improvement.

Can you give examples of creativity in engineering? After the 2011, 2012, and 2013 Creative Engineering courses, students reported +0.9, +0.86, and +1.03 improvements. The largest improvement in 2013 correlated to the lowest pre-course self-assessment (3.69 vs. an average of 4.01 in the first two years).

Can you use tools to be more creative? The 2011 self-assessments showed the largest improvement (+1.7 points vs. +1.22 and +1.01 in 2012 and 2013, respectively). In addition, the 2011 course also had the highest post-assessment (4.8/5.0 vs 4.35/5.00 and 4.55/5.00 in 2012 and 2013, respectively). We believe the larger improvement and better overall score in 2011 was due to the more expensive creativity class. However, the 2013 course pre-assessment was markedly higher than the 2011 and 2012 assessments. Therefore, it may be that students would not see the same +1.7 point improvement in future years if the Creative Engineering class reverted to the more expensive external organization creativity class.

Can you explain how to be more creative? The 2011 self-assessments showed the largest improvement (+1.78 points vs. +1.07 and +0.70 in 2012 and 2013, respectively). In addition, the 2011 course also had the highest post-assessment (4.3/5.0 vs 3.79/5.00 and 4.00/5.00 in 2012 and 2013, respectively). We believe the larger improvement and better overall score in 2011 was again due to the more expensive creativity class. However, the 2013 course pre-assessment was again markedly higher than the 2011 and 2012 assessments. Therefore, it may be that students would not see the same +1.8 point improvement in future years if the Creative Engineering class reverted to the more expensive external organization creativity class.

Can you explain the role of a leader in the creative process? The 2011 self-assessments showed the largest improvement (+1.6 points vs. +1.37 and +1.36 in 2012 and 2013, respectively). However, the post-assessments in 2012 (4.42/5.00) and 2013 (4.36/5.00) showed higher final scores than the 2011 course (4.3/5.0). Therefore, it may be that students would not see the same +1.6 point improvement in future years if the Creative Engineering class reverted to the more expensive external organization creativity class.

Following the 2012 and 2013, additional questions were asked in the post-course assessment. Students were asked to rate each part of the course as either Excellent (5 points), Good (4 points), Average (3 points), Below Average (2 points), or Poor (1 point). This was done in an attempt to understand the relative weighting students made on the various components of the trip to determine in the future if components like the 2011 more expensive class should be offered or not.

As shown in Figures 3 and 4, the students overwhelmingly viewed the overall trip as "Excellent," with average scores of 4.89/5.00 and 4.91/5.00 in 2012 and 2013, respectively. In addition, the scavenger hunts and other professor-facilitated activities are also viewed as "Excellent" (4.89/5.00 and 5.00/5.00 in 2012 and 2013, respectively).

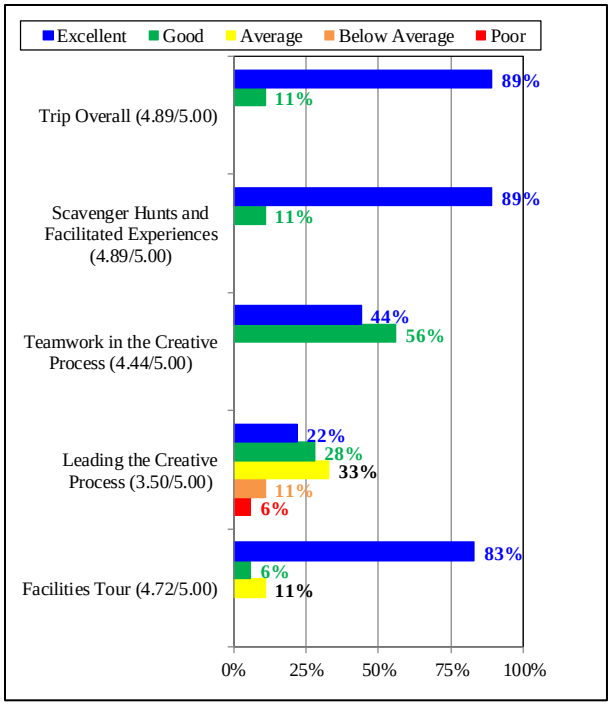

FIGURE 3: Histogram of student ratings of individual components of the 2012 Creative Engineering course from Excellent (5) to Poor (1).

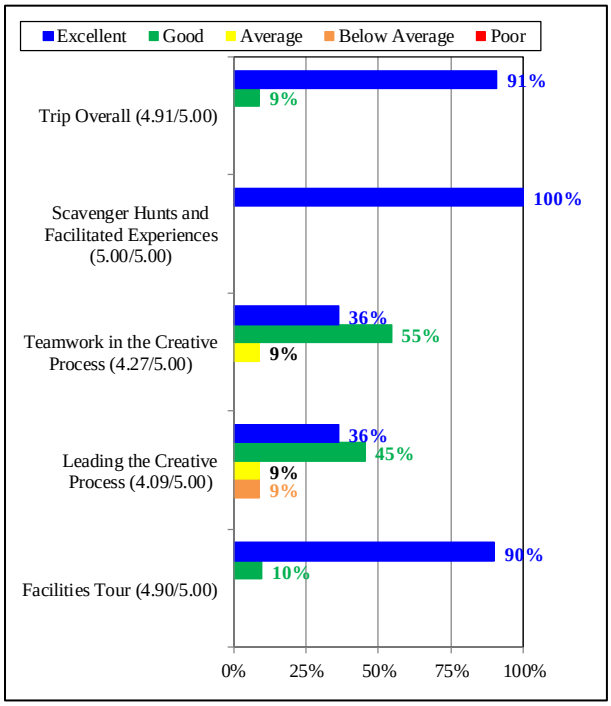

FIGURE 4: Histogram of student ratings of individual components of the 2013 Creative Engineering course from Excellent (5) to Poor (1).

The scores for the external training organization's Teamwork in the Creative Process workshop dropped slightly from 2012 (4.44/5.00) to 2013 (4.27/5.00). It is believed that this decrease is primarily due to a decrease in the "fun-ness" of the workshop, especially considering that the 2013 course post-assessments showed improvements over the 2012 post-assessments in the "Can you use tools to be more creative?" and "Can you explain to a friend how to be more creative?"

The scores for the external training organization's Leading the Creative Process workshop improved significantly from 2012 (3.50/5.00) to 2013 (4.09/5.00). This improvement was primarily due to increasing humor and activities included in the workshop by the external training organization. Students showed similar improvements and final scores in their post-course assessment for "Can you explain the role of a leader in the creative process?" It is believed, however, that the 2013 self-assessment of the workshop would have been higher if two conditions were met by the external training organization. First, the facilities for parts of the workshop on-stage were quite noisy for a significant part of the class. Several students commented that they would have assessed the workshop more positively if the noise problems were addressed. Second, many students commented that they very much enjoyed the workshop except for the workshop's final project activity, which consumed approximately 15% of the time allotted for the workshop. The final project was seen as rather simplistic and juvenile. It is believed that if the final component of the workshop was redeveloped, the scores would have been significantly higher.

Finally, the scores for the external training organization's facilities tour improved slightly from 4.72/5.00 in 2012 to 4.90/5.00 in 2013. It is believed that the improvement in 2013 stemmed primarily from an increase in the amount of time spent back-stage on the tour.

6. SUMMARY & CONCLUSION

In this paper, we described an innovative one credit creativity and soft skills class that has been taught at the College of Engineering at Valparaiso University for the last three years. The class takes place in a non-traditional location, a theme park in Orlando, FL. Multiple modules of the class are taught by staff members of a reputable company that is a flagship for creativity. Other modules are taught by Valparaiso University faculty members using audio visual effects and real-life examples from the theme park rides and attractions. Some of these examples included behind the

scenes tours led by the theme park staff members and engineers.

The class was special, not only because of its non-traditional location but also because of its interactive, hands-on, "learning while having fun" nature. This learning while having fun encouraged the students to pay the extra costs of the class. Assessment results show that the learning objectives were successfully met and even exceeded.

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