Introducing Competition to Improve Design Aptitudes in Introduction to Mechanical Design Course

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Abstract

American products designed by American engineers are commonly considered more expensive, lower quality and slower to reach the market compared to those produced in foreign countries.[1] Responsibility for this perception could be placed upon colleges and universities for insufficiently preparing their graduates. The competitiveness of American products should greatly improve if engineering students are exposed to improved design practices early in curriculum. The Citadel Mechanical Engineering program requires 3rd-year students to take an Introduction to Mechanical Engineering System Design course, followed by a required two-semester senior design team project experience. The authors, instructors of those courses, introduced an element of competitiveness to design projects in order to stimulate student creativity and boost design outcomes. A variety of constraints, like budget, safety, reliability, ethics and social and intercultural impact were introduced. This paper describes the results of these efforts.

Keywords

Senior design, engineering design, competitiveness

Introduction

In this paper, we propose and demonstrate that a three-semester series of Engineering Design classes, culminating in a final senior design project, can be used to improve the global, team-based mindset of our students. In particular, the 3rd-year introductory course provides an opportunity to discuss product needs for different cultures, genders, and environments. Additionally, the senior design team project course, when combined with a layered competitive structure, provides an effective tool for encouraging appropriate goal setting and creativity.

The setting for this case study is a mid-sized, teaching-focused university on the U.S. East Coast that strives to graduate most students in four years. It is predominantly a fully residential cohort institution (day students), with a small cohort of non-residential, non-traditional students (evening students). There are unique student requirements that result in additional responsibilities and stress for day students, especially in engineering that requires heavier course loads to maintain academic progress. A majority of the students are male. While the students tend to be very competitive in all arenas, they have been known to form partnerships for improved academic success.

Third-year mechanical engineering students take an Introduction to Mechanical Engineering System Design course. In this course, they are introduced to certain concepts and thought processes that will be applied during the required senior design team project course. The

instructors identified that in the Introduction course the students were not creating widely applicable design solutions, such as those that would be useful in various climates or by users with anthropomorphic and biomechanic differences.

Background

Leading American companies are often criticized for designing and producing products that are more expensive, of lower quality, and slower to reach the market than those of their top foreign competitors. Some of the responsibility for this situation is put on colleges and universities for no longer preparing graduates adequately in design of robust and competitive products. Improving design practices is widely recommended[1,2] and required by ABET.

Educators are faced with the task of producing future employees who have the ability to work with teams, analyze risks, and determine a course of action. Instructional experts suggest that educational competitions offer an excellent opportunity for developing students to learn all of these skills. Capstone design courses represent an opportunity for students to take on both creative design work and a holistic real world project, yet since they are often offered at the end of engineering programs, the students have difficulty integrating their studies into real engineering situations. To increase their exposure, many suggest introducing design and competition to first-, second- and third-year courses[3]. Hands-on activities also improve student motivation, retention, autonomy, as well as teamwork, scheduling and presentation skills. Studies also show that competitive projects help establish link between different courses and to combine knowledge from different subjects to a common goal[4].

Most students would tell you that introducing competitive elements in a classroom setting creates a sense of external urgency and drama[5]. Some students rise to higher levels of academic success through competition-based learning. Students are trying to outdo their classmates and work harder. For many students, this is exactly the incentive they need to succeed at high levels. On the other hand, for some students the stress of competition is overwhelming and they may give up entirely. In fact, competition is reported to shift the participants' attention from the assignment to other factors such as efficiency, speed, and the outcome relative to the competitors. It is almost that the task becomes less important than the product[6].

Team competitions have also been successfully utilized by various employers, from healthcare professionals to industrial manufacturing, to improve engagement and learning[7,8,9].

Cultural and gender differences definitively affect how competition affects the participants. Research has found that competition is beneficial for stimulating creativity on all-male teams yet suppresses creativity on all-female teams[10].

Introducing Competitiveness to Mechanical Engineering Program

In order to improve students' design skills the instructors at The Citadel Mechanical Engineering Department decided to introduce competitiveness to their design courses. The increased competitiveness between students and student groups should result in increased creativity, new or better products and services, new or different customers and thus larger market share. Students, while competitively working on the same project, become designers, users and

stakeholders at the same time. The design process becomes co-creation as the users are actively participating[11]. The students should gain from paying more attention to details; usefulness, function and longevity of the final product; aesthetics; innovation and simplicity of the design.

Mechanical engineering students at The Citadel are exposed to design activities during their 1st-year in an Introduction to Mechanical Engineering course. The students design paper airplanes, Lego gear boxes, and water bottle rockets. The students create group reports that each account for 5-10% of their final grade.

Third-year students take Mechanical Engineering System Design (MECH 460), which is a prerequisite for the two-semester Senior Design course (MECH 481/482). MECH 460 provides experience in the integration of math, science, and engineering principles leading to a comprehensive engineering design project. Open-ended, client-based design problems emphasize a multidisciplinary approach to total system design providing multiple paths to a number of feasible and acceptable solutions, which meet the stated performance requirements. Design teams are required to develop product specifications, generate alternatives through modeling, make practical engineering approximations to include probabilistic approaches, perform appropriate analysis to support the technical feasibility of the design, and make decisions leading to an optimal system design. System integration, reverse engineering/redesign projects, human factors engineering, products liability, ethics, safety, computer-aided design, maintainability, and fabrication techniques are addressed.

During MECH 460 students are expected to design a new and improved water bottle rocket; this rocket project accounts for 30% of the final grade. Traditionally, while each team has worked toward the same goal, their projects grades were almost entirely independent of relative performance. The project grade in previous course offerings relied heavily on final report preparation (90%) and lightly on the final product performance (10%). In the present implementation, some of the product requirements, like budget, mandatory travelled distance, and performance repetitiveness, were added to augment competitiveness and improve student team performance. Additionally, project grades were redistributed so that proper documentation constitutes 50% of the grade and product performance makes up 50% of the grade. Each scheduled deliverable milestone was worth 10% of the project grade and on the day of the final testing and competition, students were able to amass up to 50% of their grade, putting additional pressure on teams to perform well on that test day. The course instructors noticed that the new project requirements produced an improvement in product performance and documentation.

The following semester in MECH 481, Senior Design I, students work in teams with four or five members on design projects furnished from external clients. The emphasis is on creating design solutions, with appropriate analyses, to meet stakeholders' needs. In addition to regular meetings with their faculty advisors, the teams are expected to maintain close and continuous communications with their clients during the semester. The projects culminate in oral presentations and interim written reports, which are submitted to the clients. The instructors of Senior Design decided to continue incorporating competitiveness in the design and by assigning the same project to multiple teams. The teams are expected to give periodic peer-reviewed

presentations; thus, the teams assigned to the same projects know about progress of their opponents.

Traditionally, each senior design team has been assigned a project that is distinct from all of the other projects. With each team working toward separate goals, comparison and competition between teams is minimal. In the present implementation of the MECH 481/482 sequence, many of the teams have been assigned duplicate projects in order to promote competition. Out of sixteen teams in this year's senior design sequence, only two projects were assigned to just a single team. All other projects had two teams working on the same project simultaneously. Thirteen teams were made up entirely of day students, two teams were made up entirely of evening students, and one team was formed from a combination of day and evening students and was one of the two teams without a competing team.

Results

At the midpoint of Senior Design I, the day and evening student teams were asked to fill out an anonymous survey regarding their perceptions of introduced competitiveness in the course. Surveyed were 58 of the 69 day students and 14 of the 17 evening students and selected results are presented in Tables 1 and 2. Table 1 refers to their experiences from the 3rd-year course (MECH 460), while Table 2 discusses competition in the 4th-year Senior Design course (MECH 481).

Table. 1. Mechanical Engineering System Design (3rd-year course MECH 460)

1 – totally disagree, 2 – somewhat disagree, 3 – neutral, 4 – somewhat agree, 5 – totally agree

		Day students	Evening students
1.	Incorporating competition in engineering design courses is necessary.	4.19	3.93
2.	Competition while working on the water bottle rocket project helped me with my ideas and designs.	4.07	3.86
3.	Competition while working on the water bottle rocket project helped me with my report.	3.90	3.50
	Selected Comments: "Competition breeds competence"		

Survey results regarding the 3rd-year course, as seen in Table 1, show that students agree that competition has a positive influence on product performance and project success. This influence is reported to affect both the design and documentation. Since all students worked on the same project in this course, they were exposed to other teams' ideas and solutions constantly. Seeing the progress of these other teams allowed students to gain design inspiration from the ideas of others as well as use other teams as a measuring stick by which to judge their own progress. Mid-project prototype testing also helped students realize whether they needed to work harder to

Table 2. Senior Design (4th-year course MECH 481)

1 – totally disagree, 2 – somewhat disagree, 3 – neutral, 4 – somewhat agree, 5 – totally agree

		Day students	Evening students
1.	Are you aware of another team working on the same project at The Citadel?	82%Y 18% N	79%Y 21% N
2.	I feel like I am in competition with another Citadel team.	3.33	2.79
3.	Having competition should help me design a better product.	3.82	3.07
4.	Having another Citadel team working on the same project helped me with my designs.	3.14	2.57
5.	My team has been inspired by the other Citadel teams' ideas.	2.47	2.07
6.	Having another Citadel team working on the same project helped me with my prototypes.	2.53	2.14
7.	Having another Citadel team working on the same project helped me with my reports.	2.35	2.07
8.	Having another Citadel team working on the same project helped me with my presentations.	2.47	2.00
9.	I feel like my team is falling behind the other 481 teams.	2.16	2.14
10.	I feel like other 481 teams are better skilled than my team.	2.11	2.46
10b.	Specify, what your or their better skills are: "I think the teams have about the same skills but different effort levels." "teamwork" "leadership ability, motivation, commitment" "Decision making, assembling structures, building up things."		
11.	Other teams are better equipped than my team.	2.25	2.57
11b.	Specify, what makes you or them better equipped: "I feel the other advisors are more helpful" "Funding is low for our team." "life experience"		
12.	Other 481 teams are better academically.	2.44	2.14
13.	Other 481 teams have more time.	2.32	2.57
14.	Other 481 teams are more experienced.	2.33	2.21
15.	I am stressed out from the competition.	2.49	2.93
16.	I worry the competition will negatively influence my grade.	2.61	2.86
17.	If I had a choice, I would pick a project without a direct competitor.	2.56	2.64
18.	I compare my team to other 481 teams based on grades.	2.79	2.86
19.	I compare my team to competition based on grades.	2.79	2.57

perform on similar level as other students or outperform them. Evening students were overall more neutral and their survey results are lower by 0.2 to 0.4 points, or 5.5 to 11%. This

difference could be a result of the way that the students interact. The day students live in close proximity to each other and often use the same facilities to construct their prototypes, increasing the interactions where they can directly compare their prototypes to those made by other teams. Conversely, all of the evening students live off campus and many of them choose to work at their own houses or workshops outside of class hours rather than driving to campus.

Based on the survey of 4th-year students presented in Table 2, about 80% of students were aware of another team working on the same project and felt some competitiveness, which influenced their final product. The evening students on average felt neutral or disagreed that they were in competition with another team. This could be due to the fact that only two of the three evening teams worked on projects that also had another team assigned to them. The two competitor teams for these were day students, so interaction between day and evening students was minimal.

In this survey, day students on average agreed that they felt as though they were in competition and that competition helped them design a better product. On average, the students disagreed that having a competitor team helped them with individual aspects, such as prototypes, reports, or presentations, but agreed that having a competitor helped with designs, which could be due to having a wider variety of inputs from a brainstorming perspective. The strongest disagreement came from statements that other teams are better skilled, better equipped, or further ahead. This could indicate that the competition fuels a sense of team unity and students focus on the strengths of their team relative to competition.

Another difference between day and evening students speak to the negative aspects of competition. The evening students more strongly agreed to Question 15 that competition was stressing them out by 0.44 points or 17.5% more than the day students. Additionally, the evening students worried the other teams' good performance might negatively influence their grades. That said, evening students disagreed more strongly when asked if they compare their team to others based on grades. This effect could be an insecurity of feeling that they are in competition with another team, but not being able to directly compare themselves because of the separation between day and evening teams.

The questions that received the lowest responses on this survey were those that asked the students to rate their team relative to competition. On average, students disagreed that their team is falling behind and that their competition is more skilled, better equipped, better academically, has more time, or is more experienced. This could indicate that the competition fuels a sense of team unity and students focus on the strengths of their team relative to competition.

Table 3. MECH 481 Final Deliverables Comparison

	Fall 2018	Fall 2019
Final Report	**77.4%**	**88.7%**
Final Presentation	**86.7%**	**89.8%**

With the changes incorporated into MECH 481, a sizeable increase in student performance has been noted by the instructors. This is evident especially in the final reports and presentations

submitted by the students, as shown in Table 3. There is a clear improvement in final reports, particularly the level of detail relating to the project conceptualization and design ideation. The final presentations show less improvement, in part due to the fact that presentations inherently depend on the public speaking ability of individual students, but the content does show improvement over previous implementations of the course.

Conclusions

Competitive aspects were incorporated into a 3-couse junior and senior design course sequence at The Citadel in order to fuel competition and attempt to drive student performance. This increased competition was achieved in the junior level course by incorporating competitive performance benchmarks as part of students' grades on a class-wide common design project. In the senior design course sequence, increased competition was achieved by assigning multiple design teams to each project so that most of the teams had a direct comparison point and competing perspective on how to design a solution. Students reported that this competition helped them produce better designs, which is supported by significantly better final reports and presentations. Students also reported better team unity and cited aspects like teamwork and leadership that set their team apart from competitors.

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