An International Collaboration to Cultivate Global Innovators

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Abstract

This paper presents experimental evidence that divergent design in engineering is enhanced by hands-on learning. We argue that undergraduate students who are exposed early in the curriculum (before their senior year) to concepts and tools that are traditional in engineering design will deliver bolder designs, and more likely will transfer those concepts to other disciplines later in their undergraduate career. We present a collaborative effort that brings together members with expertise in science, engineering, education, media and design to develop a multidisciplinary curriculum to engage students in divergent design thinking.

Keywords: *innovation, engineering design, international collaboration*.

1. Introduction

Advancing health informatics is one of the fourteen grand challenges that has been determined by a distinguished committee of the United States National Academy of Engineering. There is a great need to create engineering talent to address world's challenges in developing next generation healthcare devices that can improve the quality of care. Several reports [1] [2] indicate that such talent can be nurtured by providing undergraduate students with a holistic approach to engineering education that includes introducing innovation and design into the existing engineering curriculum that can help improve their 21st century skills, namely, communication, collaboration, creativity and critical thinking. These skills help prepare engineers to not only become experts solely in their "hard" technical skills but also develop "soft" life-long learning skills that are essential to develop efficient products and approaches to address real-world challenges.

The need for integration of innovative and creative skills in undergraduate engineering curricula has dramatically increased over the last twenty years. It is seen that this integration helps not only combat the tendency towards fragmented curricula but also provide an integrative learning environment that exposes the students to open-ended projects and to the connections these projects make to the real-world. While access to information seems to be widespread, traditional delivery of lecture-based concepts is still performed within each university, often discipline-centric. Novel and engaging methods of teaching traditional engineering disciplines have been often mentioned as one of the major motivators for students to express their passion and becoming immersed in their fields. This will not only motivate a practice of student-centered engineering education but also allow the freedom for students to practice true engineering design which includes *failure*. Experiencing the latter would help students learn from their mistakes in their design which could be any of incorrect assumptions; lack of understanding of the problem to be solved; incorrect design specification; faulty construction; error in design calculations; incomplete experiments and data.

Education literature has established that hands-on and engaging approaches, as well as team-based learning, or “learning by doing” facilitates retention and longer lasting conceptual understanding of subjects. [3] We hypothesized that undergraduate students are more likely to better (1) apply and (2) transfer concepts learned in an innovation design course when taught with a combination of those two approaches: hands-on and team-based activities. We are also aware of cultural differences that might influence outcomes of our hypothesis tests, and of assessment mechanisms that might skew data. We have implemented a workshop with 75% of hands-on or construction activities (versus lectures), and a final project that involved prototype-building and demonstration of tools learned during the workshop. Our objective is to encourage innovative design.

The international and interdisciplinary collaborative effort took place between two universities (George Mason University, in Virginia, USA, and POSTECH, in Pohang, Korea). We piloted a ten day, three hours per session workshop on Innovative Design, targeted at freshman to senior level undergraduate students from a variety of disciplines. The course was taught by a team from Engineering, Computer Science, Mathematics, Economics, and Education fields. The workshop took place in POSTECH (Pohang, South Korea), and all students were of Korean origin, attending the university at the freshman, sophomore, or junior levels. Majors ranged from engineering to physics, and jewellery design. Hands-on activities were interspersed with short lectures on research and tools in engineering design. Student teams (3 to 4 students each) selected a final project that tackled a healthcare issue in Korea, and went through the design cycle, applying tools usually taught in creativity courses and innovation design. The tools included engagement of the students in multiple representations to problem solving, affinity mapping for collaborative brainstorming, blogging for personal reflections, lateral thinking for thinking outside the box, prototyping for concept generation, collaborative sketching and 6-3-5 methods for brain-writing, six thinking hats for role playing, divergent thinking for identifying problems and SCAMPER techniques for generating multiple solutions. In this paper we report on the insights from that experience for the students and instructors, on the results from hands-on activities as well as their final projects, and we establish data points for comparison with American teams of similar educational background.

2. Methodology

The instructors met over the six months prior to the workshop and collaboratively developed a syllabus based on learning outcomes desired. The instructors co-designed and delivered the workshop as a team, not individually, differently from traditionally co-taught classes; all team instructors were present and participated in the sessions. This also served as a process that allowed the instructors to systematically examine our collaborative approach, with the goal of becoming more effective each day of the workshop. In this section we describe the methods used and present sample results from student work.

While several areas related to creativity and innovation were the targets of the workshop, and it was clear that we intended for a hands-on workshop, in this report we focus on the results from the engineering design portion of the workshop. Traditionally, in engineering, the design cycle starts with a needs statement (see Figure 1), then proceeds to the design of possible solutions, and the selection of one solution that is then further researched, detailed, prototyped, and tested. Associated with each phase of this cycle there are tools and concepts one could expect as part of a traditional lecture. We had previously noticed the lack of use of these tools when projects in engineering schools were delivered or executed. Here we propose to change that outcome by modifying the teaching method: from lecture-based to hands-on.

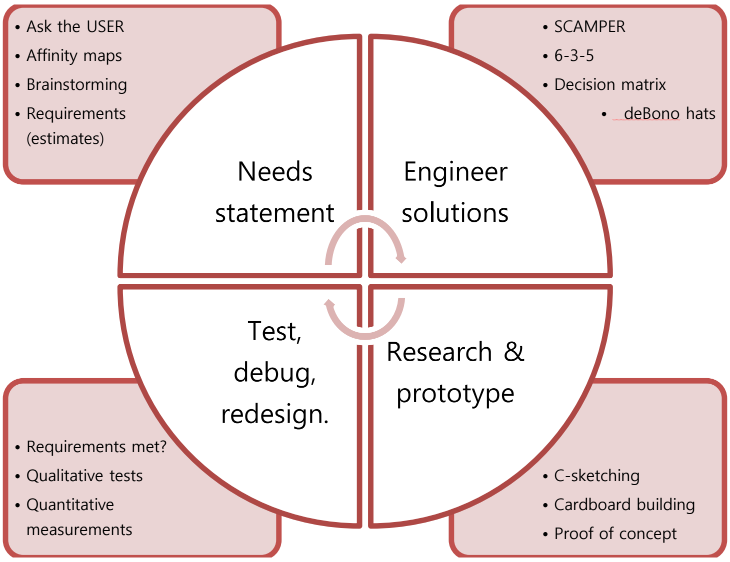

Figure 1. Engineering design cycle used to teach tools throughout the cycle. Adapted from Engineering Design textbooks. Example of design cycles can be found in [4]. This cycle assumes the beginning of the engineering design on the top left quadrant ("needs statement") but often engineers know their proposed solutions first, and then trace back which need their solution meets. Other stages in the design cycle (prototyping, debugging) are also depicted. The squares attached to each quadrant describe some of the techniques presented through hands-on activities during the workshop (details in the text).

During the intensive two week workshop, we discussed all the tools cited in Figure 1. Every discussion included a hands-on exercise. The design overview exercise was the wallet design (see Figure 2 for resulting prototypes), as proposed and developed by the Stanford d-school. [5] This is a two-hour activity from warm-up to debriefing that takes students through the several phases of the design cycle, culminating with testing. Students performed all phases. During the building phase (usually 7 minutes), the allotted time was increased to 18 minutes, as none of the prototypes had been delivered within the first seven minutes.

Instructors noticed that, in many activities (both individual and in groups), students were designing structures or prototypes that were "safe." We use the definition of "safe design" as follows: the same tool used in many situations, similar designs across groups, designs already mentioned in class previously that are re-used, designs proposed in class are repeated in homework assignments. Instructors' previous experience with American engineering undergraduate students had shown that, when given more time and more options (more ideas generated in class, more references on the internet or from the literature), the produced designs are riskier. Engineers must be able to enact risky designs if they are to succeed as innovators. One of the proposed learning outcomes for this workshop is to enhance the innovation in designing projects. While there is no quantitative measure of innovation, one possible short-term measure is the number of divergent designs produced as a result of one activity.

Figure 2. Example of resulting prototypes from a timed activity (wallet design, as proposed by the Stanford Design School). [5]

We hypothesized that two variables prevented divergent thinking: (1) time constraint and (2) material availability. While the availability of material should not impact thinking, in hands-on activities, most students use what is more widely available, and prototypes follow the ideas generated from those materials. (past tense?) We redesigned a catapult exercise (quantitative testing activity) in order to address both of these variables. There were four groups designing catapults, with two to four members in each group. Each group designed at least two different methods of thrusting a ping-pong ball up in a parabola. One group attained a precision of 30 cm diameter (the ball always fell within 15 cm of their target, with the target located 2 m away from the catapult). While the main point of that exercise was to describe quantitative and qualitative testing, and potentially how to run statistics on quantitative testing, the students also enjoyed designing the catapults tremendously. Materials made available to students during this exercise included rulers, scissors, tape, wooden chopsticks, hot glue, elastic bands, paper cups, spoons, ping-pong balls, duct tape, clothespins, cardboard (meant as base), and trash cans (meant as targets). We did not restrict time for the design, and therefore after 90 min several groups had at least two different designs on their tables (see Figure 3 for examples of catapults).

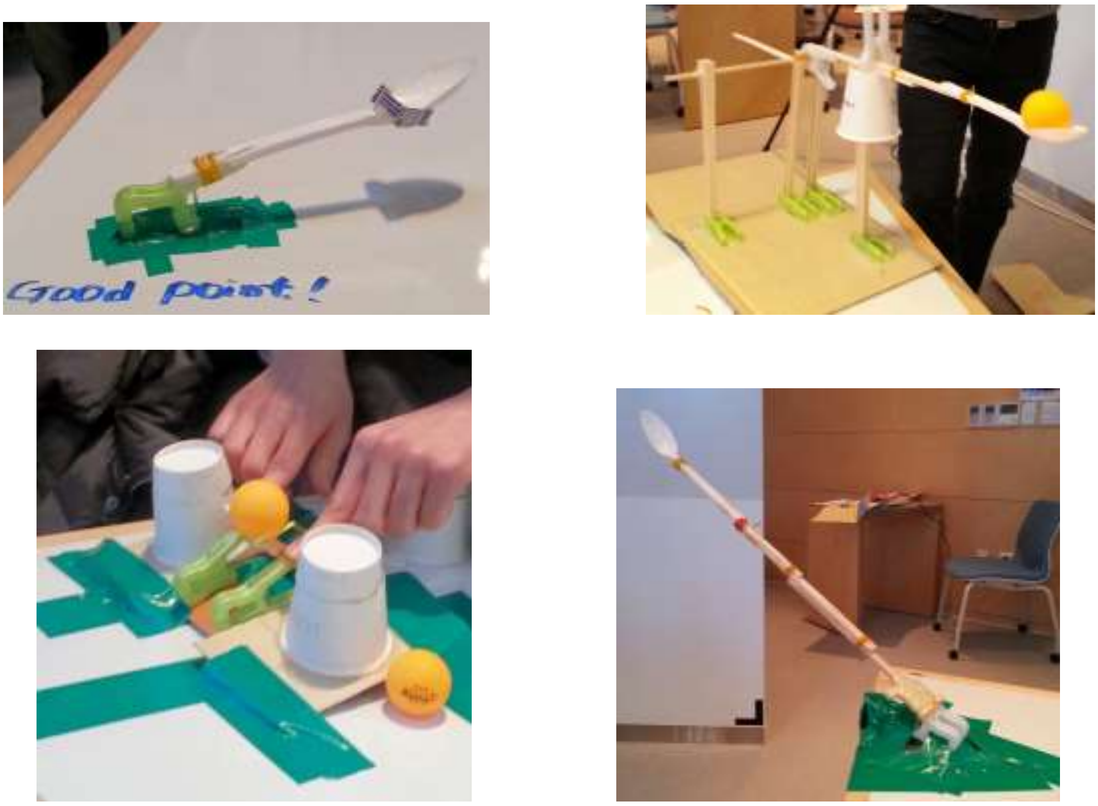

Figure 3. Examples of prototypes designed toward the testing phase of the design, with plenty of time given for alternative designs and testing. Precision was set at 30 cm. The target was a trash can, and the ping-pong balls (orange color) were used with the designed catapults. See text for details.

3. Results

During the workshop, debriefing sessions allowed for analysis of divergence observed in all design activities performed in class and requested from individual homework assignments and team assignments. Resulting designs were assessed using a rubric (see legend for Table 1) that associated higher values to diverse designs. As an example, during the marshmallow tower challenge [6], all groups used the same design (a tripod), and thus the divergence level was 1. Students reported they felt there was not enough time (18 minutes is dictated by the challenge) and that they did not have any other ideas on how to build a tower with spaghetti. We should point out that the main objective of the marshmallow challenge was to emphasize that “fail early and often” leads to better design. This point was discussed through several other activities during the workshop. We present, in table 1, a summary of the activities, the allotted time for each activity (12h means a homework assignment that is due the next day), and the divergence level.

In contrast to the marshmallow challenge, which was one of the activities during the first day of the workshop, the catapult design (Figure 2) was performed during one of the last days. Divergence of the design was graded at level 5, which is the highest grade. Students felt more confident, but also had previously failed in many other activities. While they were given many materials, the materials were not specific materials for building catapults. Each group designed at least one failing catapult (failed to achieve precision imposed as a requirement of the design) but that did not seem to prevent new designs. This was the main expected outcome of the innovative design activities: to fail and learn from failure, in order to adapt and then design the next-generation, transformative, successful design.

As a culminating activity, students designed a final project that documented their creative engineering design process. They were asked to show critical steps during their project with a link for each project on a blog account with a short video (example of a final project documentation can be found in [7]. The final presentation was the key deliverable for this course. As students learned different tools and ways of thinking, they used those tools to advance their own design challenge and included those components in their final presentation. Although each group's presentation content and form was different from one another, the design thinking approach for each project focused on these critical ideas:

- Statement of the design challenge
- How the team went about recruiting/finding potential users
- Actionable insights based on the design research conducted
- Key themes and opportunity areas identified from the insights
- Visualized concepts that address the opportunity areas
- A compelling, human-centered narrative that ties all the points above together
- What was done well and what needed improvement after user feedback or user study.

Table 1. Activities and their associated divergence level observed in the resulting prototypes. The sequence presented here follows the two week workshop deliverable dates (activities are not in alphabetical order). Rubric for divergence level is as follows: many divergent designs presented as "answers" to one activity (5); only one design per group or per person presented, but there were several designs as a whole (for the whole class) (3); only one or two design idea used by the whole class, idea used was previously shown or discussed (1,2).

activity	time	level
marshmallow tower	18min	1
balsamiq design (app)	12h	2
zoometools tower	40min	2
newspaper design	12h	1
word cloud design	12h	1
wallet design	18 min	3
catapult design	90min	5
glasses scamper	20min	2
final health care project	2 weeks	5

4. Discussion

The theme of the workshop helped the students visualize the key differences between levels of design including adaptive (which involves adaptation of existing designs); developmental (which involves starting with an existing design but ending with a considerably different design than the initial one), and newer (which involves generating a novel concept using previous skills with inclusion of creativity, insight as well as futuristic thinking). This educational experiment of enhancing creativity for innovation design includes components of engineering design brought together multidisciplinary and multinational perspectives that helped to improve the quality of the course in a formative fashion.

The students presented final projects that included research on the general (global) problem of healthcare. The solutions proposed definitely leveraged the global aspect of each project.

5. Conclusion

Here we have demonstrated that sequential hands-on activities increase the number of ideas generated and may increase the retention of concepts taught. We intend to expand the methodology presented in this report to a wider audience of students and compare design results and concept transfer across populations.

6. Acknowledgements

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