Using Design Thinking Tools to Promote Innovation in Engineering Students

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Abstract

This paper presents an empirical study focused on examining the outcomes from a course designed to promoting innovation through an instructional intervention consisting of design thinking and project-based teaching practices and assessment methods for undergraduate engineering students. Design thinking is a key process that encourages iterative thinking for engineer students as they apply their discipline specific knowledge to solving real engineering problems. Using the phenomenological approach, the researchers present finding from the analysis of classroom artifacts (posters, models, prototypes, reflections and presentations) with individual interviews and survey data.

Keywords: teaching and learning strategies, innovation; engineering design

1. Introduction

This study focuses on a phenomenological study examining the outcomes from a course designed to promoting innovation through an instructional intervention consisting of design thinking and project-based teaching practices and assessment methods for undergraduate engineering students. Design thinking is a key process that encourages iterative thinking for engineer students as they apply their discipline specific knowledge to solving real engineering problems. The design thinking process involves understanding a problem through empathy, defining the issue at hand through problem formulation, generating many possible solutions through ideation, prototyping several solutions and testing the solutions and getting feedback. The process involves students having dispositions that embraces experimentation, accepts failure and leverages it for redesign, persists through setbacks to reiterate for better solutions. In our study, we examined how designing an engineering course focused on design thinking and project based learning could provide opportunities to develop/elicit attributes of innovators within engineering students. A multi-disciplinary team of faculty co-designed and co-taught a course for 14 undergraduates in the field of electrical engineering, mechanical engineering, physics, Creative IT Engineering and Design. The course consisted of 10 three-hour sessions over two weeks and another two weeks for group projects. One of the major intervention in this study was the implementation of the design thinking process using nameable tools aimed at promoting creativity and design thinking (i.e. C-Sketch, SCAMPER, DeBono’s thinking hats, and affinity mapping). Students were given the problem of designing an innovative device to improve health care. We collected classroom artifacts (posters, models, prototypes, reflections and presentations) with individual interviews and survey data. We used these different data sources to triangulate the data to find recurring themes. Our paper will share some of the key findings, such as how engaging students with design tools helped them be more versatile in their thinking and gave them tools to use for their divergent and convergent thinking to enhance their product design. For many engineering students, the design activities helped them understand a logical yet iterative cycle that includes research, empathizing with the user, defining the problem and generating creative solutions, prototyping and testing to get feedback to loop through the cycle again that can help them improve on an innovative engineering design. Finally, through many of the collaborative tools, students experienced a concrete
experience of what synergy looks like when working collaboratively on a common goal of designing an innovative device for health care.

2. Methodology

The participants included a total of 12 undergraduate engineering majors and 2 design majors. The course was face to face for 10 days for 3 hours followed by another 10 day period for the groups to finalize their final projects. The co-designed course was delivered and co-taught by an interdisciplinary team consisted of faculty from engineering, mathematical sciences, education and technology. Using a phenomenological approach we examine the following two research questions:

1) How do the activities and strategies presented complement the goals of promoting 21st century skills including, creativity, critical thinking, communication and collaboration?

2) How do students view learning through the design thinking process and how do they self-assess themselves on different attributes that are attributed to innovators?

We implemented the Multi-tiered Design Research approach (Lesh & Kelly, 2000) to collect data from two sources of participants: the first level was the student-participants and the second level was the instructional team. We felt that because the team was made up of a unique team of multi-disciplinary faculty, that getting the different perspectives would be invaluable for this study. To organize the data from the two levels, we collected student artifacts and reflections through classroom assignments, blog entries, reflections and individual interviews. To collect the data from the instructional team, we asked each faculty member to keep a memo of their reflections from key activities. These memos allowed us to examine the course design as well as the impact these intentionally designed experiences had on student development especially documenting the instances that marked students’ creative output, design thinking, and specific student learning outcomes.

3. Results

First, we will share a synthesis of the analysis of key activities and strategies that were presented in our course and how these promoted 21st century skills including, creativity, critical thinking, communication and collaboration, in addition to some of the attributes of innovators. Second, we will share survey results that reveal students’ responses to learning through the design thinking process and how they view themselves on different attributes related to innovators.

Key Learning Activities that Promoted Creativity, Critical thinking, Communication and Collaboration

In this section, we present the key activities that were designed to promote creativity, critical thinking, communication and collaboration and the themes that emerged from our instructor’s memos and students’ reflections and artifacts.

In Sessions 1-2, we focused on the Discovery Phase: Insights Generation, where we had students discover and create a project space that defined the areas of interest for themselves. To start this we asked students to create a blog introducing themselves and also sharing a bit about their passion in life and some specific health care issues in their world that they care about. The instructional team wanted them to share broadly about their passion but then to also be specific with the prompt about the health care. The blog was a way for the students to keep a “diary” of their process but also a design method to catalogue their impressions, record interviews with others about health care, and keep track of their observations of people as they interact with products, services and environments while identifying areas where health care problems occur. In class, we did many hands-on construction and design activities. The first of which was building a tower with limited materials like spaghetti and marshmallow to impress upon them the idea of designing and redesigning with quick prototypes. There were design tools that were introduced each day, such as the mock up tool called Balsamiq, that allowed them to think about designing a mobile app interface that could help people in everyday life. They were given an opportunity to be creative with their storyboards.

In session 3-4, we focused on the Design Phase: Concept Generation. We introduced students to a variety of brainstorming techniques. In doing so we encouraged communication and collaboration by using brainstorming as a method to enable a team to work together to generate ideas quickly and effectively. Some specific brainstorming tools were called Collaborative Sketching and the 6-3-5 technique that helped manage the generation and selection of design alternative. One particular brainstorming strategy called SCAMPER, which stands for Substitute, Combine, Adapt, Modify, Put to another use, Eliminate, and Reverse, was done with a
product like eyeglasses where students used critical thinking skills while engaging in the problem-finding and solution finding process. When asked to rate the degree to which these design tools helped them in their final project design process, the SCAMPER tool, Free Flowing Brainstorming and Getting Feedback and Redesigning were the ones that were rated as providing the greatest help (see Figure 1).

![Figure 1. Helpfulness of Brainstorming Tools to Final Design Projects](image)

The instructional team thought through these sessions a lot in terms of the sequence of activities. The design tools introduced in week 1 would be integral to the design process for the team projects. The course was documented through a website and a blog at [http://citewinter2014.tumblr.com/](http://citewinter2014.tumblr.com/).

In sessions 5-6, we focused on the Delivery Phase: Concept Definition where the instructional team shared the group project assignment with a rubric. We asked them to define a problem in healthcare that can be addressed with engineering and information and communication technology. The statement of the design challenge included having each team identify these components:

- How you 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/user study

In addition, we asked each team to keep a record of their iterative design thinking process (see Figure 2). The important aspect of the design process was noticing how the arrows go both ways and can revert back to any part of the stages in the design and redesign stage. We modeled these different phases of the design thinking process with the Stanford D-school’s Wallet exercise, which was a good way for the students to experience this cycle to use for their own group project.
For session 7-8, we focused on *Delivery Phase: prototyping and testing* where we defined testable requirements. As an instructional team, we talked a lot about having the students experience what it means to test their prototype to get qualitative and quantitative results. This was related to part of their rubric where we wanted them to learn more about item 7 on our rubric: “7. Used information collected (qualitative and quantitative data utilizing methods) during the testing of the prototype to improve the product. Redesigned and retested the product until the design goal and design requirements were met (e.g., through debugging, optimizing, even documenting failure and redesign. Therefore, we had them start session 8 interviewing their client from the wallet project to obtain “qualitative” interview. In addition, we decided that another creative construction project would allow them to experience the design engineering cycle again, so we decided on the “catapult design”. This activity had two main goals: 1) to re-experience the design engineering cycle with quick prototyping and 2) to collect quantitative measures to test the prototype and improve the product. To be sure the students understood the parameters set for their experimentation, we gave a mini lesson on the difference between accuracy vs. precision. This turned out to be a great activity to bring the idea of collecting quantitative data to improve on the product design. Next, we introduced the decision matrix to help the students consider different design options (see Table 1).

Table 1. Example of a decision matrix from a student group to weigh in important design features

<table>
<thead>
<tr>
<th>Criteria, Requirements, Constraints</th>
<th>Cost</th>
<th>Ease of Use</th>
<th>Safety</th>
<th>Ease of Manufacturing</th>
<th>Durability</th>
<th>Comfortable to Wear</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Weights (1-10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>keep cool with refrigerant</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>7</td>
<td>107</td>
</tr>
<tr>
<td>sensor kit</td>
<td>3</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>8</td>
<td></td>
<td>135</td>
</tr>
<tr>
<td>wear for atopy</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>6</td>
<td>107</td>
</tr>
<tr>
<td>for fitness center</td>
<td>6</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>111</td>
</tr>
<tr>
<td>sensor on skin</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>7</td>
<td>103</td>
</tr>
<tr>
<td>gloves and socks</td>
<td>6</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>126</td>
</tr>
<tr>
<td>apply for jump rope</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>96</td>
</tr>
<tr>
<td>link to computer</td>
<td>2</td>
<td>2</td>
<td>7</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>107</td>
</tr>
</tbody>
</table>

Finally, to help students prepare for their final presentation, we shared other student projects from past courses that have improved other people’s lives, such as a design project where a student designed a wheel chair that was operated by one’s humming voice for a quadriplegic and students liked seeing others like them were building prototypes and presenting their work publically.
In session 9-10, we focused on the Delivery Phase: Feedback and Selling your ideas. They had a chance to begin building their models and/or begin rapid prototyping. We discussed the differences between models and prototypes. The groups had more work time while the instructional team walked around giving feedback and posing questions. This style of teaching and learning is often called studio-based teaching and learning because it resembles how an art teacher might circulate around the studio giving feedback to students. In session 10, each team needed to make a presentation to “sell their idea”. Students presented their concept and artifacts for review in moderated, public sessions and received design feedback. The design feedback also allowed for formative evaluation. Faculty and peers gave feedback using the de Bono’ thinking hat that provided diverse perspectives. The next 10 days were provided for groups to meet outside of class to develop the final video and prototypes that were uploaded on the team blog for final evaluation. Some of the final project ideas are shown below (see Figure 3).

Figure 3. Examples of Student Design Thinking Projects

Students’ perspectives on learning through the design thinking process and their self-assessment on attributes of innovators

To address our second research question, how do students view learning through the design thinking process and how do they self-assess themselves on different attributes that are attributed to innovators, we created a survey and used the final individual exit interviews to analyze for recurring themes.
### Table 2. Students’ self-assessment of innovative traits

<table>
<thead>
<tr>
<th></th>
<th>1-Need more development</th>
<th>2-Need some development</th>
<th>3 somewhat good at it</th>
<th>4 Very good at it</th>
<th>5-This is my strongest area-strength</th>
<th>Total</th>
<th>Average Rating</th>
</tr>
</thead>
</table>
a) Questioning. Innovators are questioners who show a passion for inquiry. They ask questions to understand how things really are today, why they are that way, and how they might be changed or disrupted. | 0% | 41.67% | 25% | 25% | 8.33% | 12 | 3.00 |
b) Observing. Innovators are also intense observers. They carefully watch the world around them—including customers, products, services, technologies, and companies—and the observations help them gain insights. | 0% | 16.67% | 50% | 25% | 8.33% | 12 | 3.25 |
c) Networking. Innovators spend a lot of time and energy finding and testing ideas through a diverse network of individuals who vary wildly in their backgrounds and perspectives. | 8.33% | 25% | 33.33% | 25% | 8.33% | 12 | 3.00 |
d) Experimenting. Finally, innovators are constantly trying out new experiences and piloting new ideas. Experimenters unceasingly explore the world intellectually and experientially. They visit new places, try new things, seek new information, and experiment to learn new things. | 8.33% | 25% | 25% | 33.33% | 8.33% | 12 | 3.08 |
e) Persistent. Innovators are never above a task; they are hardworking, persistent and willing to do whatever it takes to get things done. | 0% | 41.67% | 0% | 33.33% | 25% | 12 | 3.42 |
f) Committed to learning. Innovators stop in and participate and they continually seek knowledge. | 8.33% | 8.33% | 41.67% | 33.33% | 8.33% | 12 | 3.25 |
g) Visionary. Innovators are highly imaginative, maintain a future orientation, and think in mental pictures. | 0% | 25% | 33.33% | 25% | 16.67% | 12 | 3.33 |
h) Celebrate diversity. Innovators choose to work with a purposeful and diverse collection of people and see them to differentiate. | 16.67% | 25% | 16.67% | 25% | 16.67% | 12 | 3.00 |
i) Flexible/Adaptable. Innovators can handle uncertainty, initiate new projects and are able to adjust the ‘game plan’ as needed. | 16.67% | 33.33% | 16.67% | 16.67% | 16.67% | 12 | 2.83 |
j) Listen. Innovators are open to input from all parties, learn quickly from feedback and take them on board in the outcome. | 8.33% | 16.67% | 8.33% | 41.67% | 25% | 12 | 3.58 |
k) Take Risks. They go beyond their comfort zone, have courage and take calculated risks. | 0% | 33.33% | 33.33% | 16.67% | 16.67% | 12 | 3.17 |
l) Fail. Innovators are not afraid to fail. They bounce back from disappointment and try again. | 16.67% | 33.33% | 25% | 8.33% | 16.67% | 12 | 2.75 |
m) Desire for improvement. Innovators respond to deep inner needs, increase efficiencies, and offer enhanced experiences to improve processes for a better return on investment. | 0% | 16.18% | 9.09% | 45.45% | 27.27% | 11 | 3.82 |
n) Social mind with interest in public benefit: the innovator pursues and promotes public interest. | 8.33% | 25% | 41.67% | 16.67% | 8.33% | 12 | 2.92 |
o) Open mind with professional ethics and integrity: When the innovator realizes higher mistake, the innovator swallows pride in public and self-correction oneself instead of trying to justify it. | 8.33% | 25% | 16.67% | 41.67% | 8.33% | 12 | 3.17 |
The Self-Assessment of Innovative Attributes was a great inventory to help understand the areas of needs these students had in terms of areas of opportunities these students might want to seek out to develop these important attributes. For example, if it is important for engineering students to understand that part of the design processes is to “fail early, fail fast and fail often” to yield a breakthrough in innovation then classroom environments need to allow for failure and iterative redesign. The results from the survey showed that item 1) Fail and item k) Take risks in order to innovate, were two of the attributes with lower self-assessment scores. It may be important to help students understand the idea that innovators are not afraid to fail, they bounce back from disappointment and try again. It is interesting to note that students also rated a related attribute low, which was item i) flexibility and adaptable: Innovators can handle uncertainty, initiate new project and are able to adjust the “game plan” as needed. This may be a hard attribute for many Korean students where their lives have been so structured and lock step. It may be an overgeneralization but many Korean students go through a routinized school life. It may not surprise anyone that the Korean students are the highest in self-assessing their attributes in the two items e) persistence and m) desire for improvement.

4. Discussion

We propose that the survey we created with the attributes of innovator be used more as a metric to help students develop in areas they feel like they need more exposure and experience. During the four years that engineering students go through the program, this inventory can be used to measure how much they feel like they are developing in these areas as they go through well designed opportunities through the program. For example, it may be that having more service learning projects that allow students to think beyond their specific major and think for the broader welfare would help develop more of the social mindedness that was listed as item n) Social mind with Interest in public benefit: the innovator pursues and promotes public interest.

The designed activities were great starting points to get students exposed to these important skills and attributes. For example, we wanted to encourage students to ask questions, item a) question. In fact our instructors’ first Korean words were, “JIl-mun heyo!”=Ask questions! The students were very reserved and reticent in asking questions. We asked them to ask more questions of their peers, thinking that maybe they were restrained because they were not used to questioning a faculty member. Even then, the questions were hard to come by. We asked them to question in Korean which helped some engage in more questioning but still, as an instructional team, we felt the frequency of questions was lower than expected. We hypothesized that the language barrier and the difference in seniority of students might have some cultural barriers in questioning one another but this was more of our hypothesis and our own wondering about cultural differences. In general, we felt that students needed to be exposed to more of an inquiry stance to learning. There are many educational initiatives that can be recommended to enhance this inquiry stance.

5. Conclusion

Some integrative educational initiatives that we might recommend for students to be more exposed to an inquiry stance to learning are listed below.

- Undergraduate research with a mentor with an annual research symposium
- International Competitions to showcase research and development
- Develop co-op programs as an integral part of inquiry based learning
- Offer cross-college research collaboration for hybridization
- Introduce cross-disciplinary professionals for convergence of ideas

To support some of the recommended integrative educational initiatives mentioned above that promote students’ inquiry stance to learning, the current research environment will need to allocate resources in these endeavors and provide more opportunities for students to connect with multi-disciplinary faculty to engage in research as co-researchers. In additions, students need more opportunities for public presentation where they share their research where they assume the role of students as scholars. These initiatives will allow for more networking opportunities for students that may lead to formal and informal mentoring and collaboration that may lead to innovative ideas and projects.

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References

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