Research Initiation: Enhancing the Learning Outcomes of Empathic Innovation in Biomedical Engineering Senior Design Projects

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Abstract

One of the aims of biomedical engineering is to facilitate the development of innovative technologies to address socioeconomic challenges in healthy living and independent aging. Realizing such innovations requires empathy, agility, and creativity. This project aims to support the professional development of a competent biomedical engineer workforce that can effectively accomplish emphatic innovation, and one that can frame and re-frame problems through the innovation process. Our research examined how engineering students empathize with users and develop empathic abilities that have implications on their design innovation skills. The project team developed empathic innovation workshops and embedded them into existing biomedical engineering capstone courses. Data were collected using surveys, student project reports, ideation tasks, and observations. These workshops resulted in significant changes in students' emphatic tendencies. From our qualitative studies, we also conjectured that the overall empathic potency of a student design team helped facilitate problem re-framing based on user input. These findings contribute to the literature on the critical role of innovation behaviors in relationship to empathic design tendencies in the context of biomedical engineering, as well as suggest instructional practices designed to promote empathy, agility, and creativity.

Introduction

User-centered biomedical technology development is critical to the well-being and care of at-risk populations, including the elderly and disabled. However, it is challenging to teach the engineering innovation of technologies. The challenge mainly lies in equipping the students with technical and professional competencies in developing user-centered solutions during the innovation process. In this project, we aim to facilitate the professional development of biomedical engineering (BME) students with an emphasis on gaining competencies in engineering design through empathic innovation. We have examined and continue to examine the following three questions:

1) How do undergraduate engineering students' emphatic design tendencies and abilities evolve over time through a multi-semester sequence of BME capstone design?
2) To what extent do undergraduate engineering students' empathic tendencies relate to the framing and re-framing process in their capstone design projects?
3) To what extent do undergraduate engineering students' empathic tendencies relate to their engineering innovation in their capstone design projects?

We found interventions, like holding empathic innovation workshops in capstone design courses, led to changes in students' emphatic tendencies. Our findings also suggested a student design team with good overall empathy potency could facilitate problem framing re-framing towards satisfying user-specific needs. These findings contribute to the literature of user-centered design learning in the context of biomedical engineering where it is much needed.

Project Scope

This research initiation project aims to facilitate the professional formation of BME students in user-centered BME. Building on a framework of empathic innovation, our goal is to produce strategies for successful professional development of BME students for user-centered innovative design.

Our specific objectives are:
1) To assess the aspects of empathic innovation (i.e., empathy tendencies, empathy potency, framing/re-framing, innovation tendencies/potentials);
2) To design workshops on empathy, re-framing, and design innovation;
3) To produce research and evidence on student changes; and
4) To develop a framework for empathic innovation.

Assessing Aspects of Empathic Innovation

Assessing empathic design tendency

Many well-established instruments exist to explore general empathic tendencies, beliefs, behaviors, but engineering provides a unique context. Empathy, a complex construct with many related constructs, involves both cognitive and affective components as well as orientations that can be self-centered, other-centered, or pluralistic. An instrument that examines emphatic tendencies in the context of engineering does not exist. Using the interpersonal reactivity (IRR) model [1] of empathy's dimensions (Figure 1), we created the Empathic Design Tendency Survey (Appendix A). These items were then evaluated with experts outside the project team and found to be in alignment with the framework. Using this instrument, we collected survey data at two time points: February 2019 and September 2019. While we collected survey data from individual students, we also developed a new metric to determine team emphatic potential, namely, "collective empathic tendency."

Self-oriented + Affective **Empathic Distress** (experiencing stress)	Other-oriented + Affective **Empathic Concern** (feeling concerned)
Self-oriented + Cognitive **Imagine-Self Perspective Taking** (imagining self)	Other-oriented + Cognitive **Imagine-Other Perspective Taking** (imaging the feeling of other)

Figure 1. Empathy types (based on [1])

Assessing Innovation Potential

In the literature, we identified several ways of assessing innovation potential. We approached the assessment of innovation potential in two ways. First, we used a coding protocol that evaluates design solutions (brainstormed or final solutions) [2 – 4]. We assessed innovation potential by analyzing students' design ideas reported in their final project reports and project presentations. Our second approach was to use the Innovation Self-Efficacy Survey developed by Schar and colleagues at Stanford University [5]. Using this survey instrument, we collected data in October 2019. Both the innovation potential coding protocol and the Innovation Self-Efficacy Survey were developed based on the Innovator's DNA framework by Dyer et al. [6] with five behaviors that were shown in engineering [7]: questioning, observing, associating, experimenting, and networking (Figure 2).

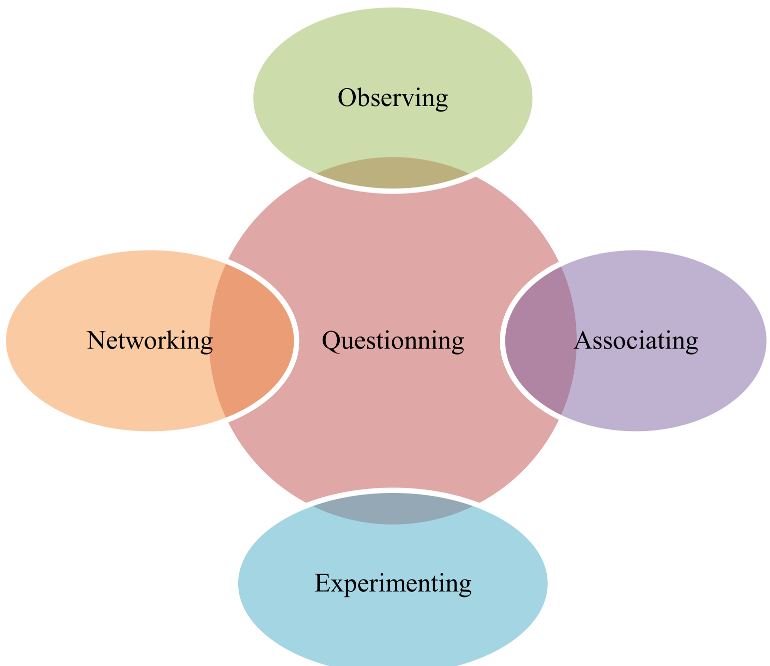


Figure 2. Key innovative behaviors

Assessing re-framing

We conducted one pivoting reflection survey in April 2019. With this instrument, we collected data on problem framing and re-framing. We analyzed final project reports and project presentations from the junior design course (BME390) in spring 2019 for problem framing and re-framing.

Data Collection Process/Timeline

The research team collected data on framing and re-framing, innovation tendencies, innovation potential, and innovation tendencies from 60 – 70 BME undergraduate students between February 2019 and December 2019.

We designed another ideation workshop in November 2019 in which we asked the students, in pairs, to provide solution ideas on a biomedical engineering design task for improving medication adherence. The pairs were created based on the students' empathy tendencies. From the workshop, we collected data to calculate students' innovation potential.

We interviewed the team leader of the two selected teams on framing and re-framing in November 2019.

Empathic Innovation Workshops

The research team successfully ran three workshops on empathy, pivoting, and innovation. Three workshops were held in February 2019, April 2019, and November 2019.

Empathic design workshop (February 2019)

The workshop in February 2019 started with an instructor presentation on empathy, followed first by a survey on empathy tendencies, and then followed by an ideation exercise on developing a visual aid tool for visually impaired people (Figure 3). To facilitate the survey, we included the video clips of interviews with technology developers for visual aid tools and real people who suffer from visual impairment. We also prompted the students to get familiar with the circumstances of visually impaired people by asking them to wear googly glasses and, at the same time perform simple tasks such as writing their names reversely in a text file and checking the real-time weather information on the internet.

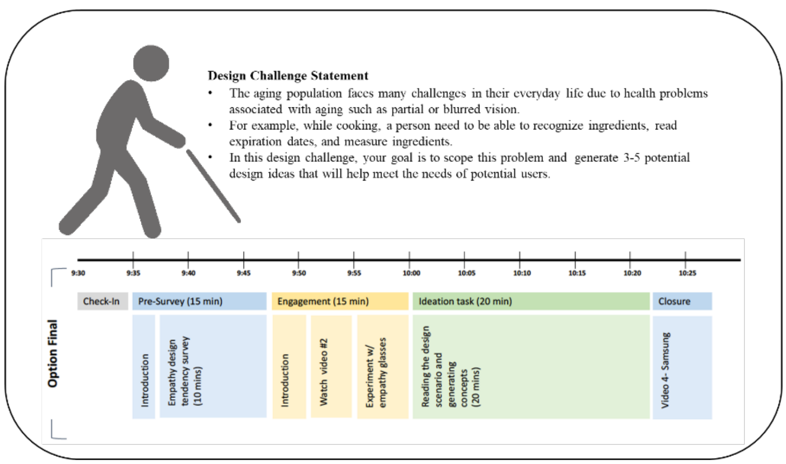


Figure 3. Emphasizing with visually-impaired

Pivoting and re-framing workshop (April 2019)

The workshop in April 2019 started with an instructor presentation on his pivoting experiences in the past working on aging-related technology development projects (Figure 4), followed by having students conduct self-reflection on pivoting with a set of self-developed prompts. At the time the workshop took place, many groups of students already conducted problem framing and re-framing. Hence, before the self-reflection task, there was a segment of in-class discussion eliciting students' experiences on framing and re-framing in the past few months and their experiences prior to the junior capstone course.

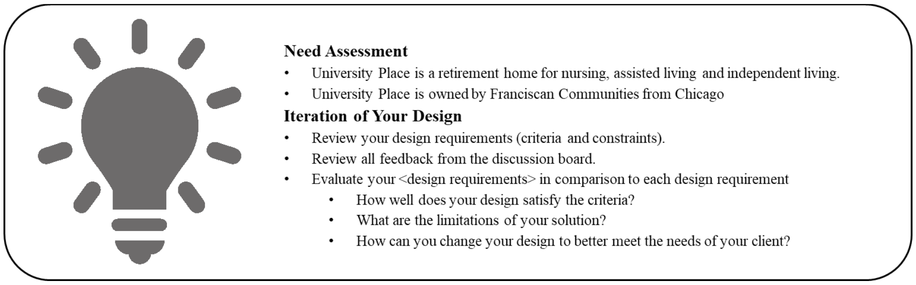


Figure 4. Overview of the instructor presentation

Innovative design workshop (November 2019)

The November 2019 workshop included three ideation exercises on the same challenge but with different perspective emphases and different levels of information provided. The ideation task, designed for this workshop, focused on improving medication adherence for a patient with chronic diseases. We provided the students with a real-world end-user so they could focus their design solutions on meeting the needs of target patients. A patient's daily activities and medical needs were also included in the workshop to promote a sense of empathy with the expectation of a viable and desirable solution for end-users. The workshop was conducted with three parts in a progressive manner (see Figure 5). For the first part, we provided each group of two students with a brochure that contains information about medication adherence. We included definitions, statistics, facts, and factors that impact medication adherence. We also provided a design scenario, design specifications, and a description of target customers. During the second and third parts of the workshop, the design scenario, target customers, and design specifications remained the same. Moreover, we provided additional contextual information about other stakeholders involved in the drug dispensing and medication system (the second part), and additional technical information about current smart pill bottles and dispensers available on the market (the third part). For each of the three parts of the workshop, we collected design solution ideas.

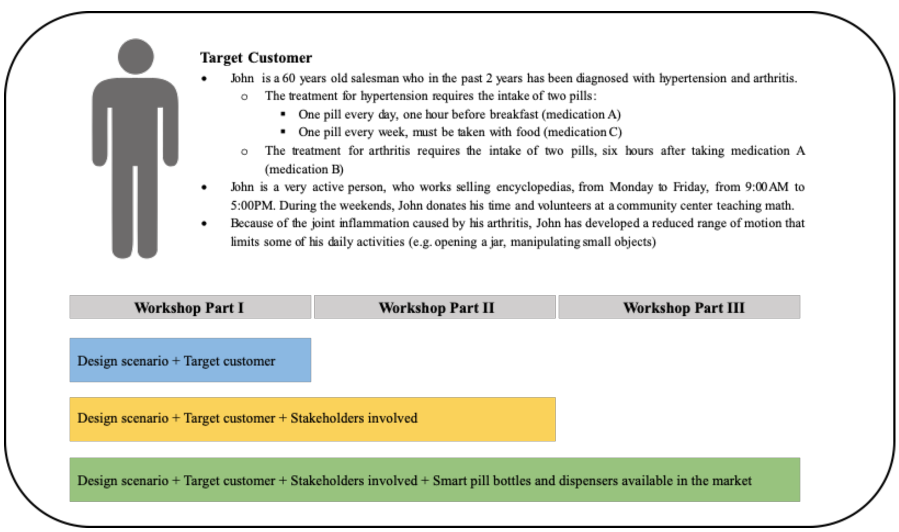


Figure 5. An overview of the design ideation workshop

An Exploratory Framework for Empathic Innovation

We developed a conjectural framework based on theory and prior research on emphatic design, innovative design, and engineering education. Our research findings so far have shown that empathic abilities and innovation abilities are connected by the re-framing behavior of designers (Figure 6). We will continue to evaluate this preliminary framework and refine it in future stages of the project.

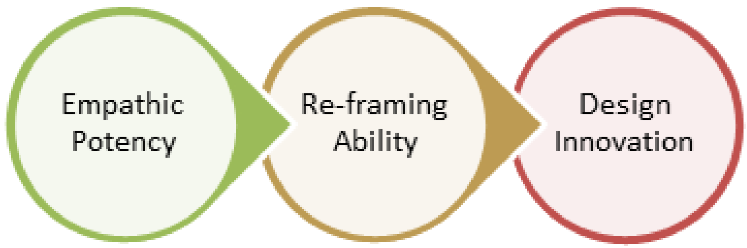


Figure 6. An exploratory framework for emphatic innovation

Results

Research Question #1: How do undergraduate engineering students' emphatic design tendencies and abilities evolve over time through a multi-semester sequence of BME capstone design?

Data Collection and Analysis: Data were collected through the Empathic Design Tendency survey at two different points (February 2019 and October 2019). The survey was administered via Qualtrics. We identified the same cohort to take both surveys. When the pre-survey took place, these students were junior students in their sixth semester; when the post-survey took place, these students had become senior students in their seventh semester.

Key Findings: For each of the three constructs of empathy (i.e., image-other; image-self; and empathic concern), the improvement was statistically significant. The three improvements across the sub-constructs of empathy were at about the same magnitude, i.e., increased by roughly 25% from between 4. 5 – 5 to between 5.5 – 6 in a 7-point scale (Figure 7).

Recommendations: The workshops offered as part of this project were beneficial to the students' thinking of empathy during design innovation and using empathic techniques more conscientiously and confidently. Through a preliminary root cause analysis, we recommend scaling up the practice of encouraging students to conduct more interviews with end-users and domain experts with more detailed guidance on the user interaction, e.g., asking the students to regularly keep a journal on their interactions with end-users and domain experts. We also recommend additional workshops on empathy, especially on the use of empathic design techniques during the sixth semester. Of course, such recommendations should be taken with caution. One possible alternative cause was student internship during summer 2019 between the two surveys. Many students could have gained more exposure to the importance of empathy within engineering through such experiences.

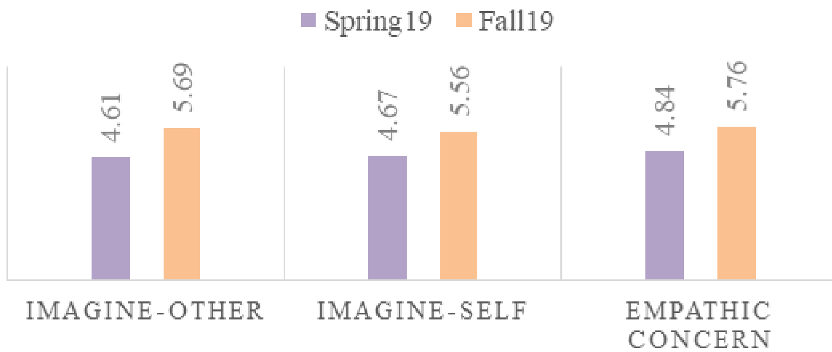


Figure 7. Changes between pre and post empathic tendency scores (Spring19 vs. Fall19, N=61)

Research Question #2: To what extent, do undergraduate engineering students' empathic tendencies relate to the framing and re-framing process in their capstone design projects

*Data Collection and Anal*ysis: Data were collected using four different methods: an open-ended question on framing, empathic tendency survey, final project reports and presentations developed by the students, and interviews of selected students with the instructors. Both quantitative and qualitative approaches were used in the analysis.

Key Findings: A slight majority of the students reported making re-framing decisions (i.e., pivoting) related to empathy. The variety of reasons of making the decisions included changes in target users, problem statements, solution ideas, target markets, and other business-related issues. The students cited the information that prompted re-framing was often from stakeholders, but they also used literature review results, as well as user and instructor feedback. Re-framing led to conducting more research and interviews, as well as deeper idea generation and team discussion (Figure 8). Further evidence on students' emphatic tendencies were identified in students' explanations such as the desire for helping users and valuing user and stakeholder feedback. The motivational and emotional reactions to re-framing ranged from better motivated and confident to more frustrated and stressed.

Recommendations: Given our finding illustrating a link between empathic tendency and re-framing, we recommend that engineering education help prepare students for re-framing in two ways: 1) with cognitive tools that provide student with tools and strategies to collect, use feedback from users and other stakeholders, and 2) with emotional tools that prepare students to value re-framing and deal with the frustration and disappointment associated with change.

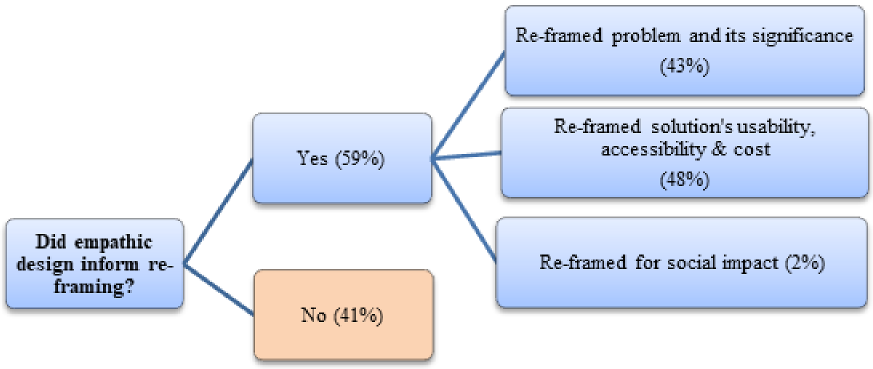


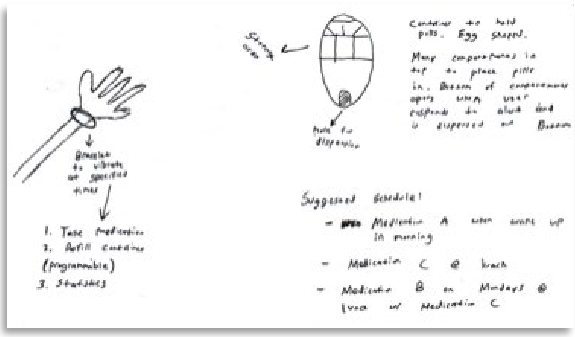
Figure 8. Re-framing decisions and empathic tendency [8]

Research Question #3: To what extent do undergraduate engineering students' empathic tendencies relate to their engineering innovation in their capstone design projects?

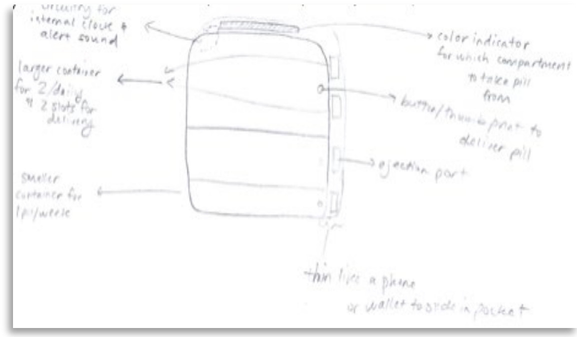
Data Collection and Analysis: Data for this study were collected from a capstone design project course in the BME program of a large research university in the Midwest. Sixty-four students participated in an in-class ideation workshop for developing digital health solutions for improving medication adherence of a specific targeted user. The primary data used in developing an assessment instrument for user-centered innovation potential among biomedical engineering undergraduate students was the solution ideas generated by the participants. Students completed a submission template where they sketched their design diagram and listed the design specifications. In the response, each student group included labels, descriptions, and justifications based on the information provided in the design scenario.

Key Findings: The most common idea identified by the participating BME students was a pill dispenser with a programmable panel and an integrated alarm system that provides notifications at specific times. The most novel idea identified by the reviewers was a bracelet, with a built-in system to hold medications (Figure 9). Through the workshop, groups adjusted their ideas based on the additional information provided. An adjustment made by many groups was involving pharmacists and physicians in the process of improving medication adherence. For example, one group proposed a pill dispenser in part one, and adjusted their design in part two to incorporate a programmable console expectedly operated by the pharmacist and physician who are in charge of setting the dosage for each medication and filling the dispenser (See Figure 9). Other groups adjusted their designs for portability, or to improve patients' reliability by collecting and sending real-time data of medication intake to the physician.

Recommendations: Based on the re-framing process many groups experienced from part one to part two of the workshop, we concluded that the design of the ideation task and the way by which the information is delivered, is crucial for the students to design ideas that are user-centered. To promote user-centered innovative thinking for this case study, information has to go beyond stating the medical need and include details on the circumstances where the solution will be applied. Therefore, the role of biomedical engineering educators becomes crucial to help raise students with self and social awareness during their design thinking process. The in-class ideation workshop described above creates an opportunity to improve the student's skills in thinking broadly about the design context and recognizing their responsibility for promoting better biomedical engineering practices.



Innovation Potential Score: 80



Innovation Potential Score: 3

Calculation of Innovation Potential = Novelty Score x Feasibility Score x Desirability Score

Figure 9. Sample design ideas for innovation potential scores [9]

Conclusions

This project aims to explore ways to assess two aspects of empathic innovation, namely empathic potency and design innovation, as well as their connection through problem framing/re-framing. Our findings contribute to the literature on the critical role of innovation behaviors in relationship to empathic design tendencies in the context of biomedical engineering, as well as on the need to design instructional practices to promote empathy, agility, and creativity. In the future, we will validate the assessment instruments, refine study protocols, and conduct larger-scale cohort studies. We will soon build on the current momentum from this seed grant project to scale up our study.

Acknowledgments

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Appendix A

Empathic Design Tendency Survey

The purpose of this survey is to reflect on a recent engineering design project and think about the strategies you used during this project. On the following pages, you will be asked a series of questions related to this project experience. The survey will take approximately 10 minutes to complete.

*For the **first part of the survey**, we would like to know a little bit more about this project and how you built empathy with the user.*

Think about a recent engineering project you <u>have completed</u> (meaning not your capstone project)

1. Please briefly describe the recent engineering project you are thinking about.
2. During this project, to what extent have you interacted with potential direct users?
3. What methods have you used to learn about direct users (e.g., their context, needs, etc.)?

*For the **second part** of the survey, please read each statement below and rate your level of agreement based on the same recent engineering project that you described earlier. The responses are on a scale of Not at All True of Me (1) to Very True of Me (7). There are no right or wrong answers.*

While reading or hearing about the design scenario:		**Not true at all**						**Very true**
1. I imagined the users' everyday activities within their real-life context.	Imagine-Other	1	2	3	4	5	6	7
2. I felt sorry for the user experiencing the problem.	Empathic Concern	1	2	3	4	5	6	7
3. I imagined how I would feel if I experienced the problem.	Imagine-Self	1	2	3	4	5	6	7
4. I felt that I was able to relate to the challenges the users experience in their everyday life.	Empathic Concern	1	2	3	4	5	6	7

5. I imagined challenges that I would experience everyday if I were the user.	Imagine-Self	1	2	3	4	5	6	7
6. I imagined how the users would feel when they experience the problem.	Imagine-Other	1	2	3	4	5	6	7

While generating my design ideas:		Not true at all						Very true
7. I imagined what design criteria would be the most important to the users.	Imagine-Other	1	2	3	4	5	6	7
8. I felt happy when generating ideas that can be helpful to the users.	Emphatic Concern	1	2	3	4	5	6	7
9. I imagined how my ideas would look from the users' perspectives.	Imagine-Other	1	2	3	4	5	6	7
10. To generate more design ideas, I imagined how I would feel if I were the user.	Imagine-Self	1	2	3	4	5	6	7
11. I generated ideas imagining that I were the user	Imagine-Self							
12. I hoped that my ideas would be useful for the users.	Emphatic Concern	1	2	3	4	5	6	7

While evaluating my ideas:		Not true at all						Very true
13. I felt concerned when my ideas did not meet the needs of the users.	Empathic Concern	1	2	3	4	5	6	7
14. I imagined how I would use my ideas if I were the user.	Imagine-Self	1	2	3	4	5	6	7
15. I imagined why the users would like my ideas.	Imagine-Other	1	2	3	4	5	6	7
16. I imagined why the users would dislike my ideas.	Imagine-Other	1	2	3	4	5	6	7
17. I felt happy when my ideas helped the users.	Emphatic Concern	1	2	3	4	5	6	7
18. I imagined what problems I would have when using my ideas if I were the user.	Imagine-Self	1	2	3	4	5	6	7
19. I imagined what aspects of my ideas users would find enjoyable.	Imagine-Other	1	2	3	4	5	6	7
20. I evaluated my ideas by imagining that I were the user	Imagine-Self	1	2	3	4	5	6	7

Appendix B

Innovation Self-Efficacy Survey

The purpose of this survey is to reflect on your confidence in innovation behavior and the project you are working on this semester. On the following pages, you will be asked a series of open-ended and rating questions. The survey will take approximately 10 minutes to complete.

The following question is about your thoughts on innovative projects. Please answer the question.

What are the most important criteria or aspects for a project to promote innovation in biomedical engineering? Please list your top three - one is the most important.

- 1.
- 2.
- 3.

Use the slide bar to rate how likely you are to perform each of the following activities from 0 (Not Confident) to 100 (Extremely Confident).

Experimenting

Experiment as a way to understand how things work

Experiment to create new ways of doing things
Be adventurous and seek out new experiences
Actively search for new ideas through experimenting
Take things apart to see how they work

Questioning

Ask a lot of questions
Ask the right questions to get to the root of a problem
Ask more questions than my classmates
Ask the kind questions that change the way others think about a problem
Ask questions that challenge fundamental assumptions
Ask questions to understand why projects or designs underperform

Idea Networking

Build a network of people for new perspective, refine my ideas
Seek advice of students and faculty to test ideas
Reach out outside of my major to spark ideas for a new product or service
Build a large network of contacts, get ideas for new products or services

Observing

Think of new ideas by watching people interact with products and services
Generate new ideas by observing the world
Observe how people use products and services to help me get new ideas
Pay attention to everyday experiences as a way to get new ideas

Associational Thinking

Connect concepts and ideas that appear, at first glance, to be unconnected
Connect ideas from different and diverse areas

The following questions about the project you are working on this semester. Please answer the questions.

1) How are you personally contributing to the project? Please describe your specific tasks.

2) What innovation skills did you learn by participating in the project?

3) What was most challenging about the project?