Problem Reframing and Empathy Manifestation in the Innovation Process

Mrs. Eunhye Kim, Purdue University-Main Campus, West Lafayette (College of Engineering)

Eunhye Kim is a Ph.D. student and research assistant in the School of Engineering Education at Purdue University. Her research interests lie in engineering design education, engineering students' social processes (shared cognition and group emotion) in interdisciplinary design and innovation projects. She earned a B.S. in Electronics Engineering and an M.B.A. in South Korea and worked as a hardware development engineer and an IT strategic planner in the industry.

Dr. Senay Purzer, Purdue University-Main Campus, West Lafayette (College of Engineering)

enay Purzer is an Associate Professor in the School of Engineering Education.

Carolina Vivas-Valencia, Purdue University

Carolina Vivas-Valencia is a Ph.D. student in the Weldon School of Biomedical Engineering at Purdue University, West Lafayette IN. Her research interests lie in simulation modeling and optimization in population health, healthcare data analytics and outcomes research, community-based health operations research, and innovation education in engineering.

Dr. LINDSEY B PAYNE, Purdue University-Main Campus, West Lafayette (College of Engineering)

Dr. Lindsey Payne is a Director in the Office of Engagement at Purdue University coordinating service-learning programs and initiatives. She has a courtesy appointment in Environmental and Ecological Engineering where she teaches a service-learning course in which interdisciplinary teams of students collaboratively identify stormwater management problems, co-design solutions, maintain budgets, and evaluate impacts with community partners. Dr. Payne's research sits at the intersection of sustainability, teaching and learning, and engagement focusing on transdisciplinary decision-making frameworks in community-based design projects. She also specializes in the assessment of instructional effectiveness and student learning in active learning environments. She is the recipient of multiple teaching awards, and is the Chair of the Teaching Academy. She has a B.A in Biological Sciences from DePauw University and M.S. and Ph.D. degrees in Ecological Sciences and Engineering from Purdue University. She has also worked professionally in the non-profit and secondary education sectors, and currently serves on multiple community-based environmental boards.

Dr. Nan Kong, Purdue University at West Lafayette

Nan Kong is an Associate Professor in the Weldon School of Biomedical Engineering at Purdue University. He received his PhD in Industrial Engineering from the University of Pittsburgh. His research interest includes big-data health and social well-being data analytics. He is actively in collaborating with international partners to enhance American engineering students' global learning.

Problem Reframing and Empathy Manifestation in the Innovation Process

Abstract

In the innovation process, design practice involves multiple iterations of framing and reframing under high levels of uncertainty and ambiguity. Additionally, as user desirability is a significant criterion for innovative design, designers' empathy in the framing and reframing process is considered a critical user-centered design ability that engineering students should develop. In this context, this study aims to discuss how problem framing and empathy manifestation interplay in the innovation process. As an exploratory study, this study investigates biomedical engineering (BME) students' reframing processes and decisions in a one-semester design project involving problem definition and concept identification. This investigation is guided by the following research questions: 1) how do engineering students perceive the relationship between empathy and reframing in the innovation process, 2) how and how often do they make reframing decisions over the stages of problem definition and concept identification, and 3) how different are reframing processes and decisions between teams with higher and lower empathetic design tendency scores? This study was conducted in a junior-level design course of 76 BME students. We collected and analyzed three data sources: students' self-reflection reports about their reframing processes, empathic design tendency scores, and interviews with selected teams and instructors. The results demonstrated that more than half of the students perceived the connection between empathy and their reframing decisions and that they usually had one reframing moment in the stages of problem definition and concept identification. Also, the findings suggested the triggers for their reframing moments, information sources guiding their reframing processes, changes made through reframing, and influences of reframing decisions on team project processes. Furthermore, the comparison of the selected two teams revealed two differences in reframing processes between the high and low empathic design tendency-scoring teams. The authors believe that the study expands engineering education research on engineering students' empathy and problem-framing by illustrating students' reframing processes throughout a design project and exploring the interplay of empathy and reframing processes. Also, based on our study findings, engineering design educators can promote student empathy development by including more project activities and evaluation criteria related to empathic design and providing formative feedback on their reframing processes.

Introduction

As framing and reframing is thought of as a core design principle, especially for innovative design, design education research has studied how designers approach a design problem situation in the framing and reframing process [1-5]. Engineering education research has also investigated how engineering students frame and reframe a problem situation, emphasizing the importance of students' cognitive abilities to approach and structure an ill-structured design scenario. Additionally, some studies examined how much time students spend exploring a given problem situation and identifying design requirements and constraints [6-8]. On the other hand, there have been studies that counted the numbers of critical issues or stakeholders that students identify in the given problem situation [9-12]. Murray, Studer, Daly, McKilligan, and Seifert [13] explored what strategies engineering students use in the process of exploring and framing a design situation and identified a total of 27 strategies across different design problems. The strategies include breaking down the primary user and stakeholder groups, stating the primary need, and describing the setting and environmental conditions. Furthermore, Atman et al. [7] compared freshmen and senior students with experts. Their study illustrated that compared to the students, the experts allocated more effort for framing at the early stages of the design process, and revisited and revised their frames multiple times throughout the design process. All of the studies discussed above suggested that we need more studies on how students go through framing and reframing processes and how to help them engage in the processes more effectively in educational settings.

Meanwhile, engineering students' empathy is increasingly considered to be a critical engineering design aspect in innovation contexts. Engineering education also has discussed how students can learn empathic design approaches in engineering design learning environments [14]. Some studies illustrate how engineering students employ an empathic design process and techniques in their course project [15-19]. Hess and Fila [14] explored how empathy functioned throughout students' design projects in a service-learning course, and Fila, Hess, Purzer, and Dringenberg [20] examined how students develop and utilize their empathy towards users during a design task without direct interaction with users. Furthermore, Beckman and Barry [21] discussed students' empathy in problem framing. They explained that at the first stage of the design process, empathizing with the students allows them to interpret a problem situation with users' perspectives. It implies that empathy is essential in framing and reframing processes.

In consideration of the importance of engineering students' framing and reframing processes and empathic design abilities, there have been critical work surrounding their problem-framing and empathy. However, there is still a gap in understanding of engineering students' iterative reframing processes and the role of empathy in these activities. To fill this gap, this study explores biomedical engineering (BME) student teams' one-semester journey to create the most effective frame in a design project. This exploration will be guided by the following research questions (RQs):

> **RQ 1**. How do engineering students perceive the relationship between empathy and reframing in the innovation process?
>
> **RQ 2**. How and how often do they make reframing decisions over the stages of problem definition and concept identification?
>
> **RQ 3**. How different are their reframing processes and decisions between the teams with higher and lower empathetic design tendency scores?

Literature Review

Design Problem Framing & Reframing

As a design situation is typically open-ended and ill-structured with a high degree of freedom in its representations, processes, and solutions [22-23], a designer should interpret, transform, and structure before solving the problem [2]. This process is referred to as framing [24]. It engages the designer in outlining the current situation and desired outcomes, as well as identifying goals, rules, critical issues, and relationships among them [25]. In a product design context, Bjorklund [1] investigated how experts frame a design situation by interviewing 14 designers after asking them to read and analyze a given design scenario in a limited time. Her investigation determined that the experts drafted a frame of the situation by identifying important and missing information, goals and sub-goals for the project, requirements and initial ideas for the product, design processes, and potential challenges. These findings imply that the framing process includes defining the boundaries of attention to the problem space and then going further to the solution space.

The framing process also involves multiple iterations of reframing. At the initial stage of framing, a designer only knows what is desired in the situation (*End Value*) but does not know what is needed to achieve the value (*Thing)* and how they will operate together (*Working Principle*) [24]. Also, there can be multiple ways to achieve the end value in the situation [5], and the design situation can evolve while designers are engaged in the framing process [26]. Because of the open-ended, ambiguous, unstable nature of design situations, designers at the initial stage of framing can merely predict and infer a frame based on their best guess and assumptions [24]. Then, they explore the problem situation with the frame they created by gathering more information, seeking new perspectives, and testing their hypotheses. In this process, designers can encounter the moments when they need or want to make a change in their initial frame or create a totally new frame [24], [27] based on their incremental knowledge of the situation or any external changes in the situation. Stompff et al. [27] called this type of moment as 'surprise' in design contexts. Thus, when designers encounter a 'surprise' moment, designers evaluate and reflect on the current frame and attempt to recast it by synthesizing their previous and new knowledge and perspectives [28]. The process is referred to as reframing [24]. Several design studies determined that designers usually go through multiple iterations of reframing throughout a design project [5], [27-29].

Empathy in User-Centered Design & Innovation

In engineering education research, empathy has been conceptualized in different ways. Among them, the most common way is to define it as the ability to understand potential users' situations and emotions in design and innovation processes. In this context, several studies characterized empathy as user-oriented design thinking [20], [30-31]. Those studies commonly emphasized that engineering designers need to keep user needs at the center of the design and innovation process. Fila et al. [20] and Bairaktarova et al. [30] discussed how students understand user needs and apply their understanding to generating and evaluating solutions. Furthermore, Hess et al. [31] demonstrated significant relationships between students' empathic design tendency and innovative behaviors. More specifically, some studies described empathizing with potential users as the first stage of a design process [15-19]. They employed the design process model developed and used at the Stanford University Institute of Design, which involves the phases of *empathize*, *define*, *ideate*, *prototype*, and *test*. In this model, engineering designers listen to and understand their potential user needs at the first stage to empathize with the users [18]. In a similar sense, Beckman and Barry [21] connected students' problem-framing skills with abilities to emphasize with users. As design problems tend to be ill-structured and complex with a high degree of freedom in their representations, processes, or solutions [23], designers are required to frame a design problem before solving it [25]. Beckman and Barry [21] explained that at the first stage of the design process, empathizing with users allows students to interpret a problem situation with users' perspectives and to identify and test assumptions in framing a design problem.

Empathy has been one of the important topics in psychology, especially social psychology. Although there are multiple ways to define empathy, the most frequently discussed definitions involve cognitive and affective components of empathy. The cognitive component includes cognitive abilities to understand others' situations, experiences, thoughts, and emotional states, which is based on the theory of the human mind [32]. On the other hand, the affective component involves emotional response, such as sharing the emotions or sensory states of another person [33]. Based on this psychological concept of empathy, some design education studies developed frameworks of designers' empathy in design contexts [14], [34]. In particular, Hess and Fila's [14] framework conceptualizes the interrelationship between different empathy types. By adding the idea that empathy can be self-oriented as well as other-oriented into the cognitive and affective components of empathy, they identified four empathy types: *Imagine-Other Perspective Taking*, *Imagine-Self Perspective Taking*, *Empathic Concern*, and *Empathic Distress* (Table 1).

Table 1. *Four Aspects of Empathy*

Imagine-Other Perspective Taking	Other-oriented cognitive process. Imagine how another thinks or feels.
Imagine-Self Perspective Taking	Self-oriented cognitive process. Imagine how oneself would think and feel if they were another.
Empathic Concern	Other-oriented affective process. Feel concerned or happy for another.
Empathic Distress	Self-oriented affective process. Experience distress as a result of feeling for another.

Methods

Setting & Participants

This study was conducted in a junior capstone design project course, a prerequisite to the senior capstone design course. This junior-level, team-based course provided students with opportunities to explore a design problem for innovation in the biomedical engineering field and propose a prototypical design solution at the end of the semester (Spring 2019). Throughout the one-semester course project, each student team had two presentations. The first one was a report of the project progress and an initial version of the problem definition, and the next one was the final report, including target user description, user need statement, market analysis findings, existing and emerging solutions, gap finding, design specification, and solution identification. At the end of the course, the instructors evaluated each team's problem definition and proposed design concept. They determined whether each team's concept could be developed through a capstone design project. A total of 76 students taking this course in Spring 2019 participated in this study with each participant belonging to a team consisting of three to four members. In total there were 19 teams.

In this course, the importance of empathy and user-centered problem reframing was emphasized in multiple ways. First, student teams participated in two one-hour workshops about 1) empathic design and 2) framing and reframing in innovation processes. The workshop on empathic design occurred in Feb 2019, where the participants learned empathic design approaches and principles, and engaged in a user-centered design thinking task. In this workshop, student teams were given a design scenario about elderly population's vision loss issue. They were asked to formulate a design problem statement and generate 3-5 potential design ideas to solve the problem. To facilitate empathizing with target users, student teams viewed a video clip about the limitations of visually impaired people in their daily life and tested an artifact (translucency eyeglasses) designed for empathic experience. The workshop on framing and reframing in innovation processes occurred in April 2019. In this workshop, an instructor explained why reframing is needed for innovative design and how to make reframing decisions. For user-centered reframing, the instructor highlighted the importance of interacting with target users and various stakeholders in course projects. Beyond the workshops, the importance of empathy and user-centered reframing was stressed in the requirements of the course projects. In project final reports and presentations, each team had to identify the numbers and types of interactions with target users and various stakeholders and describe how their problem statements and design concepts are supported by the feedback of target users and various stakeholders. In addition, at the end of the course, students were given an individual assignment to reflect on their reframing process and decisions.

Data Collection & Analysis

In this BME design course, we collected three data sources, including 1) students' self-reflection reports about their reframing process, 2) empathic design tendency score, and 3) interview with selected teams and instructors. Figure 1 describes the process of collecting and analyzing each data source.

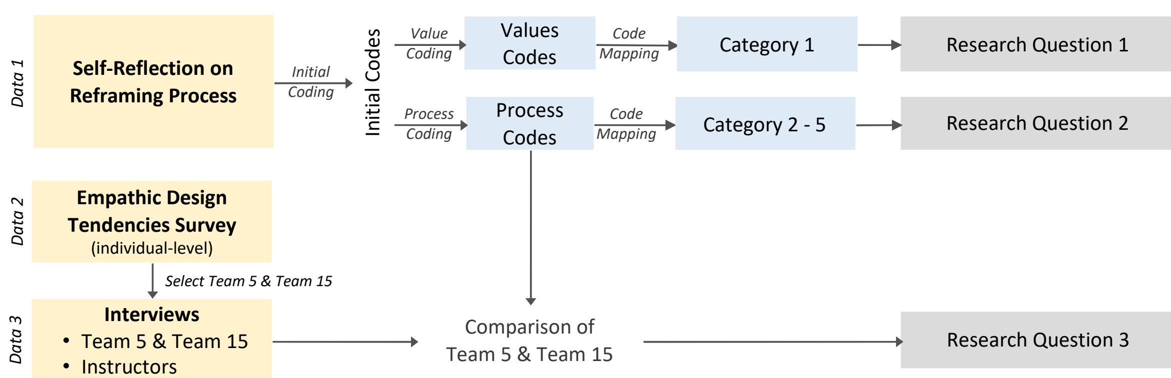

Figure 1. Data Collection and Analysis Process

Data 1. Students' self-reflection on reframing process. For their reflections on the reframing processes, we provided a list of reflective questions about the reframing decisions they had made in their design project. The list consisted of six open-ended questions:

- Do you think that your team's reframing decisions were associated with user-centered, empathic design? Why or why not?
- How many times did your team make reframing decisions?
- When was each decision made?
- What information or activities guided your team in making reframing decisions?

- How did you feel during the reframing process?
- How did reframing decisions influence your team's project process?

While participants engaged in the reframing processes of their team project, we asked them to answer the questions individually in order to look into how they personally perceived and felt in the reframing processes. The questions were distributed at the end of the workshop of framing and reframing, and they were asked to submit their answers within the week.

The reflections were analyzed through two cycles of coding with multiple methods. In the first cycle, we used *Initial Coding* with *Values Coding* and *Process Coding*. *Initial Coding* can be used as a starting point to break down qualitative data into discrete parts and examine them [35]. Through this coding method, we first identified the contents related to our research questions from the participants' answers. Then, we re-coded the initial codes through *Values Coding* and *Process Coding*. *Value Coding* assesses a participant's integrated value, attitude, and belief, and *Process Coding* focuses on actions intertwined with the dynamic of time in the data, using gerunds [36]. Using these coding methods, we can explore participants' actions, reasoning, and perceptions in the process of recognizing a need for reframing and making reframing decisions. In the second cycle, we organized the first-cycle codes into five categories, which is *Code Mapping* [36]. These categories include Category 1) the perception of user-centered reframing, Category 2) the triggers of reframing, Category 3) the information guiding their reframing processes, Category 4) the changes made through reframing, and Category 5) the influence of reframing on team project process. The coding results were used to answer Research Question 1 (RQ1) and Research Question 2 (RQ2).

Data 2. Empathic design tendency score. For measuring participants' empathic design tendency, we designed the Empathic Design Tendency Survey that consists of a series of questions related to their experiences in previous design projects. In the first part of this survey, we provided three open-ended questions about what design solutions they made in a recent project and how they learned from interacting with their target users. We intended to facilitate recall and reflection upon their previous project experiences before answering the second part of the survey. Then, in the second part, we provided 20 statements indicating how an engineering designer tends to think, imagine, and feel about users in the process of learning about users and applying their understandings into generating and evaluating design ideas on a scale of *Not at All True of Me (1)* to *Very True of Me (7)*. The statements were based on Hess and Fila's (2016) framework of empathy aspects, including empathic concern, imagine-self perspective-taking, imagine-other perspective-taking, and empathic distress. However, considering that empathic distress is a negative contributor (Hess et al., 2016), we did not measure empathic distress in the survey. We also situated each statement in engineering design contexts and processes. Table 2 includes the example statements used for measuring each of the three empathy types. This survey was formatted and distributed by Qualtrics Survey Software, an online survey tool, and completed by individual participants in the first 10 minutes of the workshop on empathic design.

Table 2. *Empathic Design Tendency Survey Statement Examples*

	Statements used in this study		
	Empathic Concern	**Imagine-Self**	**Imagine-Other**
While reading & listening to a design scenario	I felt sorry for the users experiencing the problem.	I imagined how I would feel if I experienced the problem.	I imagined the users' everyday activities within their real-life context.
While generating my design ideas	I felt happy when generating ideas that can be helpful to the users.	I imagined how I would feel if I were the user.	I imagined what design criteria would be the most important the users
While evaluating my ideas	I felt concerned when my ideas did not meet the needs of the users.	I imagined how I would use my ideas if I were the user.	I imagined why the users would like my ideas.

The collected survey answers were used to identify the teams who had generally low or high empathy design tendency score. As the survey was completed by individuals, we aggregated the collective answers at the team level by calculating each team's mean and standard deviation. Then, in the order of team mean scores, we sorted the 19 teams into four groups and selected teams having the lowest standard deviation in the first and last groups. Through this process, two teams were identified: Team 5 with the lowest mean (mean = 4.09, standard deviation = 0.35) and Team 15 with the highest mean (mean = 5.68, standard deviation = 0.88).

Data 3. Interviews with selected teams and instructors. We conducted interviews with selected teams (Team 5 & Team 15) and instructors at the end of the course to get additional insight into the differences between the teams with lower and higher empathic design tendency scores. The interviews were semi-structured with questions asking for more details of the reframing decisions each team had made in the project. The questions included: what triggered and motivated each reframing decision, how they reached the consensus on each decision, and when and how they involved users and stakeholders in the reframing process. The interviews with the two teams happened separately, and their answers were audio-recorded. Additionally, we did interviews with some of the course instructors over email. In this interview, we asked them to describe how empathic design and problem reframing had been emphasized in this course and how Team 5 and Team 15 approached the projects at early stages and went through empathic design and reframing processes based on their observation and conversation with them over the semester. The instructors' answers included the advice each team asked the instructional team and the teams' performance in the course project. The collected interview answers from the teams and instructors were reviewed along with the two teams' reflection reports, which allowed us to compare those teams' reframing processes to answer Research Question 3 (RQ3).

Findings

Category 1. Students' Perception of the Relationship Between Empathy and Reframing

The value codes mapped into Category 1 describe how students perceived their reframing decisions in a user-centered, empathic design context. To the question regarding the association between reframing decisions and user-centered empathic design, 59% of the students answered that their reframing decisions were connected to user-centered empathic design in some form. Forty-three percent stated that their reframing processes were initiated and guided by their motivation to focus on more significant problems to the users. Thirty-three percent commented that their reframing decisions were made in consideration of how users felt during product use and aimed for better usability. Additionally, some students described that they considered more user accessibility and affordability (10%), relied more on users' feedback than others (5%), and thought of social impact (2%) when making a reframing decision.

On the other hand, 41% of the students answered that their reframing decisions were not related to user-centered empathic design. The reasons behind this answer included that their reframing decisions were related to project feasibility, technology feasibility, or market viability rather than the consideration of users and user situations.

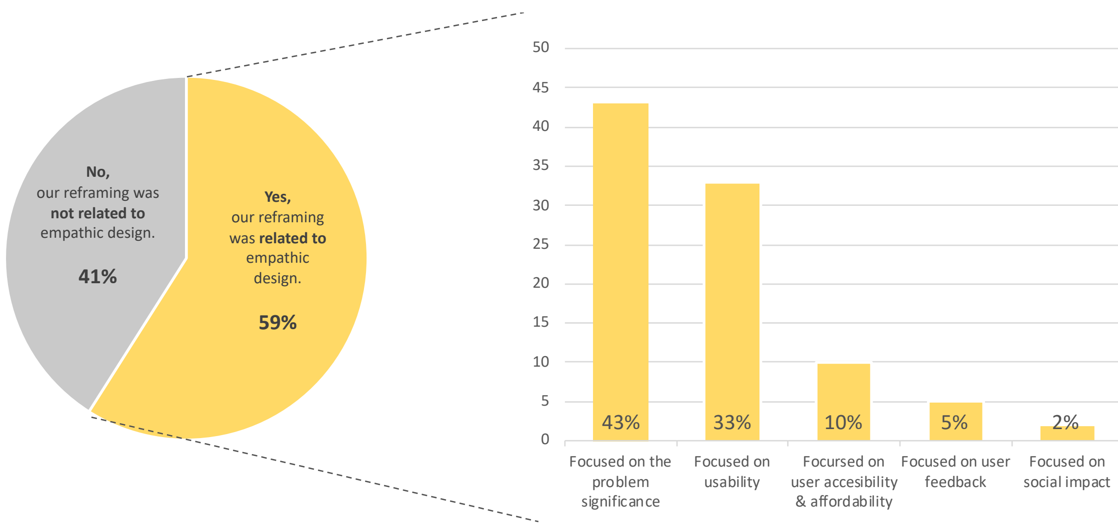

Figure 2. Students' Perception of the Relationship between Empathy and Reframing Decisions

Reframing Processes at the Stages of Problem Definition & Concept Identification

The results of analyzing the participants' self-reflection reports show how they went through reframing processes and made reframing decisions. Figure 3 describes how many reframing moments they had over the semester. Forty-nine percent had one reframing moment, and 41% had multiple reframing moments: 15% (2 reframing moments), 9% (3) times, 11% (4), and 5% (5). Six percent commented that they had not experienced any reframing moments, and two participants answered that they could not count reframing moments.

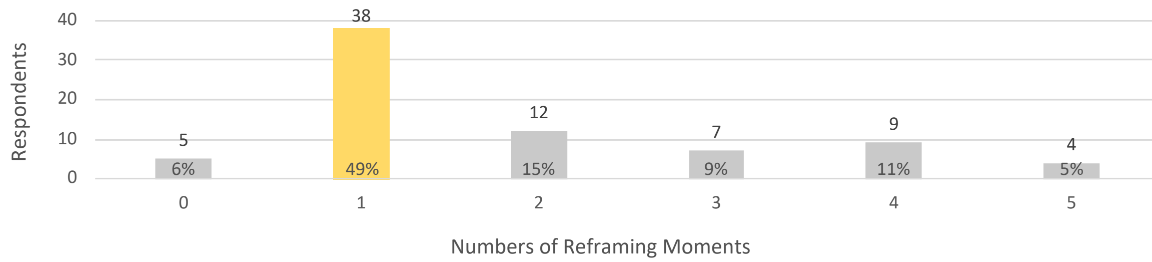

Figure 3. Numbers of Reframing Moments the Student Teams Experienced over the Semester.

Also, the coding results presented more details of their reframing processes beyond the numbers of reframing moments. For a better representation of the coding results, we developed a diagram organizing the codes of Category 2 through 5. In the following sub-sections, we will explain each category and present a diagram representing the participant teams' reframing processes in the course projects by organizing the identified codes in each category. Figure 4 reflects the relationships between categories and illustrates how and why students' reframing processes were triggered and how they made and were influenced by reframing decisions throughout the stages of problem definition and concept identification.

Category 2: Triggers of reframing. The participants reported that their reframing moments were initiated by the consideration of *the significance of a problem*, *the feasibility of creating a potential solution in a capstone project*, *the appropriate scope for a capstone project*, and *current market conditions*. First, 44% intended to focus on the problem that seemed a matter of greater emergency or related to a larger population through reframing. In terms of this point, some participants stated:

> *"We were originally focusing on how to redesign the speculum to reduce pain, then realized that it's not so much as pain for most people as general discomfort. We also found out that HPV causes almost every case of cervical cancer, so it may be better to focus on that."*
>
> *"[Reframing] allowed us to find a problem that is a little [closer] to home and impacts a larger population."*

It can be considered that this type of motivation best reflects their empathy toward users and stakeholders because they focused more on people's difficulties and needs. Additionally, 29% thought that it was important to ensure whether they would be able to develop their design concepts in a capstone project. This thought was related to the course context where their projects in this course were evaluated against the criteria related to how the proposed design concepts can be realized in a capstone project next year. In this context, they had to consider how feasible they would be able to create a solution with currently available technologies and other resources within the given timeframe.

> "*We were also limited to having only mechanical and electrical supplies for our solution, [so we had to do reframing].*"
>
> *"Upon finding this to be technically challenging, and more importantly that it would add too much time and difficulty to the measurement process, moved toward designing a cuff accessory."*

Meanwhile, 21% of the students answered that they had to consider whether their project scope was appropriate to a course project. This encouraged them to do reframing, and it can be connected to the consideration of feasibility. This motivation focused more on identifying a problem that would be appropriate to a course project at an early stage, while the motivation related to feasibility is more about generating a design concept that might be realized in a capstone design project. In this junior design course, they usually had started a specific scope and felt the need for narrowing or broadening the scope and specify their direction at some point.

> *"We originally were looking at the entire hip replacement but decided that was beyond the scope of this class."*
>
> *"He said our current diagnosing capabilities are too narrow, and we had to broaden our diagnosing capabilities."*

Furthermore, 5% of the students described that their reframing was triggered by current market conditions. They examined their target markets, potential competitors, and current solutions, which made them conclude that they would better focus on another market or customer segment.

> *"We realized that even with a good product, it may not sell due to the competitive market."*

Category 3: Information guiding their reframing processes. Regarding the information sources used in reframing processes, students identified *stakeholders' feedback* as the primary one (62%). To gather this type of information, they interviewed various stakeholders and experts, such as doctors, nurses, pharmacists, or manufacturers, depending on their design topics. Additional sources used in their reframing processes were identified as follows: *research findings* (16%), *target users' feedback* (10%), and *instructors or teaching assistants' feedback* (9%). Research included searching and reviewing academic literature, news articles, or market research reports, and users' feedback was collected by interviews with potential users. Furthermore, there was a team applying a specific decision analysis method (Pugh Analysis) learned in a previous course. Out of those various information sources, the information gathered through interviews with target users and stakeholders can be considered to promote their empathy more effectively.

Category 4: Changes made through reframing. Through reframing, they made different types of changes in their projects. Most of those changes were made related to *problem scope* (43%) and *target users* (31%) at the stage of problem definition. In terms of modifying a problem scope, they described that while maintaining a target user group, they changed the focus of the users' problem. A team who was focusing on new mothers' concerns related to breastfeeding stated:

> *"One of our main [reframing] points was switching from detecting opioids in to caffeine and finally to bacteria in breast milk."*

Compared to this change, a modification related to target users could be more expansive as the change usually led them to switch to a different design topic. For example:

> *"Our team originally aimed to find a better way to diagnose or monitor multiple sclerosis but found out that it was not feasible. We then pivoted to a completely different idea of a blood alcohol level detector."*

Beyond those two types of changes, they commented about the changes in *design concepts* (19%) and *target markets* (5%) at the stage of concept identification. The change in a design concept involved altering their product specifications or service processes, technologies or materials for their solutions, and ways to use their solutions. Also, the change in a target market included expanding their markets (e.g., into online) or shifting from end-users (e.g., patients) to healthcare providers (e.g., hospitals or companies).

Category 5: Influence of reframing on team project process. Any reframing decision required students to revisit their previous decisions and do some work over again, which could speed up or slow down their project process. They described that it required them to *conduct more research or interviews* (29%). According to their description, a reframing decision provided them with a new direction, sometimes with new user groups, which needed them to seek different information. Also, they commented that a reframing decision allowed them to *engage more in the project with more confidence* (15%), *come up with more design ideas* (14%), and *specifying actual users and stakeholders* (12%). Especially in terms of defining users and stakeholders more clearly, they described that before reframing, they felt difficulties with identifying who they should talk with and how to contact them, but which became more explicit after reframing. Furthermore, they reported that a reframing decision *broadened their perspectives of user problems* (11%), *made them feel more pressure by the shorten timeline* (11%), and *facilitated more team discussion* (8%). Their comments about increased pressure on the timeline reflected their frustration caused by the situation where they had to return to previous steps.

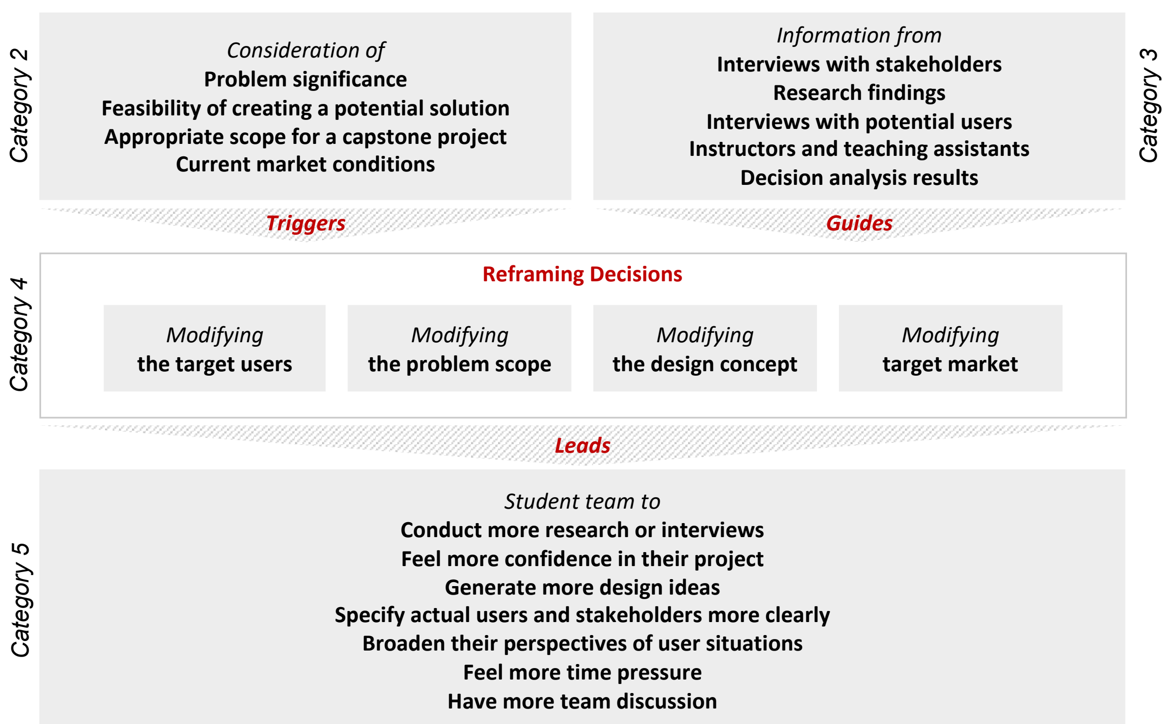

Figure 4. Student Teams' Reframing Processes in the Course Projects.

Differences Between the High- and Low-Empathy-Scoring Teams

To further explore how each student's empathy can be manifested in reframing process, we identified and compared Team 5 and Team 15 (Team 5 with the lowest score and Team 15 with the highest score of the Empathic Design Tendency Survey). We analyzed the teams' reflection reports about reframing along with the interviews with the teams and instructors. As a result of the analysis, we found two major differences between them.

First, the high-empathy-score team (Team 15) prioritized users' needs and stakeholders' opinions while the low-empathy-score team (Team 5) prioritized the feasibility of their project. In the self-reflection report, the most significant difference in their descriptions of their reframing decisions was associated with user-centered empathic design. Team 15 described that their reframing was based on their understandings of users and stakeholders, but Team 5 commented that their reframing was related to the requirements of the course project rather than users. Their interview answers support this difference. In the interview with the teams, one member of Team 15 told:

> *"Once we talked to customers, we slightly shifted [our idea] to meet customer needs. We did not completely change the project, but pivoted our focus... We also talked with professionals in the field we tried to focus on, doctors or psychologists, to know what they thought of our project and [whether] they thought that this is actually useful or needed and they might buy this product or recommend it to other people."*

When asked whether their reframing was usually triggered by internal or external input, Team 15 answered that their reframing moments were initiated by external persons and information on user needs and market conditions. Team 5, on the other hand, described that an internal conversation about feasibility initiated their reframing. One member of Team 5 said:

> *"We thought about our project for senior design, and a big challenge for us was we didn't have access to blood samples to do a lot of testing with. It would become quite expensive to create mock solutions, so we thought about budgeting on that… I think, that forced us to think about [reframing]."*

About this team, the instructors whom we interviewed stated that although the team seemed confident that the problem they were focusing on was really important, they did not have clear evidence on user needs.

Second, the high-empathy-scoring team (Team 15) tended to rely on more diverse information sources than the low-empathy-scoring team (Team 5). In the self-reflection on reframing processes, Team 15 members reported that they sought for various information and opinions from professionals, stakeholders, potential users, and instructors. One of the instructors also mentioned that this team constantly communicated with, not only an online group involving target users, but also various stakeholders and experts about their problem and design concept. The instructor also mentioned that he remembered much more about this team than the other team because this team approached him with questions more frequently. On the other hand, Team 5 reported that to gather information needed for reframing, they mainly asked stakeholders, such as doctors and nurses. One of the instructors corroborated this, stating they interviewed lots of frontline nurses and used the nurses' language in their project reports and presentations. However, related to interactions with end-users, one of the team members said that their interaction with users was not constant:

> *"We had more discontinuous communication with end-users. They did come into our class… We had a number of ideas. I remember pitching each of them to [the users] and asking them 'what is your experience with this'. The one we had*

anticipated the best feedback gave us confirmation and then [took] a few of [the ideas] to the nurses."

This answer implies that they relied more on nurses than target users even though they had the opportunity to interact with users in the course.

Discussion

This study provides some implications on engineering design education research and instruction. First, in this study, we explored BME students' one-semester journey to create the most effective frame in a design project. There have been multiple studies on students' cognitive abilities for problem-framing. Those studies usually examined how much time they spent on problem-framing during a design task [6-8] or how many design factors they identified for framing a problem [9-12]. However, only a few studies have focused on how students frame and iteratively reframe a design situation over a design project. Our findings illustrate how and why students' reframing processes were triggered and how they made and were influenced by reframing decisions throughout the stages of problem definition and concept identification (Figure 4). We believe that the qualitative findings gave engineering design researchers more in-depth insight into engineering students' framing and iterative reframing practice in design and innovation contexts. In addition, with a better understanding on students' approach and reasoning in their reframing processes, engineering design educators should give students more formative feedback.

Second, selecting and comparing two teams based on their empathic design tendency scores, we investigated how differently they approached and went through reframing processes. Both empathy and iterative framing and reframing have been discussed in engineering design education research [21]. However, there has been a lack of studies focusing on the interplay between empathy and reframing. Although our investigation of the two teams did not involve a statistical comparison test, it suggests that students' empathy influences their reframing processes and decisions. Based on our findings, students' empathy guided them to prioritize more users' needs and stakeholders' opinions and rely on more diverse information sources. In consideration of the importance of empathy and reframing practice in design and innovation contexts, we believe that there may be a need for more research on the role of empathy in framing and reframing practice. The findings also imply that engineering design educators can encourage students to have more interactions with users and stakeholders and to seek and use various information sources in their reframing processes. Considering that students' reframing processes were initiated and influenced by course project requirements, we believe that it would be effective to include more project activities and evaluation criteria related to empathic design approaches to promote students' empathy in engineering design curricula.

This study has some limitation and may require further research. The findings did not explain the relationship between students' reframing processes and empathic design abilities, which can be a limitation of this study. However, as explorative research, this study aimed at examining the nature of students' reframing processes and perceptions between empathic design and reframing decisions by collecting and analyzing qualitative data. For further investigation of the association between reframing processes and empathic design abilities, we would need to collect and analyze more various types of data through mixed-methods research design. Also, we could share the collected data with instructors and incorporate their feedback into explaining the association.

Acknowledgements

This work is based upon work supported by the National Science Foundation under Grant DUE #1738214. Any opinions, findings, and conclusions or recommendations expressed in this paper, however, are those of the authors and do not necessarily reflect reviews of the NSF.

References

[1] T. A. Bjorklund, “Initial mental representations of design problems: Differences between experts and novices,” *Design Studies,* vol. 34, no. 2, pp. 135-160, 2012.

[2] N. Cross, “Expertise in design: An overview,” *Design Studies,* vol. 25, no. 5, pp. 427-441, 2004.

[3] B, Lawson and K. Dorst, *Design Expertise.* Abingdon, UK: Routledge, 2013.

[4] N. Lotz, H. Sharp, M. Woodroffe, R. Blyth, D. Rajah, and T. Ranganai, “Framing behaviours in novice interaction designers,” in *Design Research Society 2014: Design’s Big Debates, Umea, Sweden, June 16-19, 2014,* Y. Lim, K. Niedderer, J. Redstrom, E. Stolterman, and A. Valtonen, Eds. Umea, Sweden: Umea Institute of Design, Umea University, 2014, pp. 1178-1190.

[5] B. Paton and K. Dorst, “Briefing and reframing: A situated practice,” *Design Studies,* vol. 32, no. 6, pp. 573-587, 2011.

[6] C. J. Atman, J. R. Chimka, K. M. Bursic, and H. L. Nachtmann, “A comparison of freshman and senior engineering design processes,” *Design Studies,* vol. 20, no. 2, pp. 131-152, 1999.

[7] C. J. Atman, R. S. Adams, M. Cardella, J. Turns, S. Mosborg, and J. Saleem, “Engineering design processes: A comparison of Students and Expert Practitioners,” *Journal of Engineering Education,* vol. 96, no. 4, pp. 359-379, 2007.

[8] K. M. Bursic and C. J. Atman, “Information gathering: A critical step for quality in the design process,” *The Quality Management Journal*, vol. 4, no. 4, pp. 60-75, 1997.

[9] R. S. Adams, N. Beltz, L. Mann, and D. Wilson, “Exploring student differences in formulating cross-disciplinary sustainability problems,” *International Journal of Engineering Education,* vol. 26, no. 2, pp. 324-338, 2010.

[10] H. A. Diefes-Dux and A. Salim, “Transforming the first-year engineering experience through authentic problem-solving: Taking a models and modeling perspective,” *Procedia - Social and Behavioral Sciences,* vol. 56, pp. 314-332. 2012.

[11] E. Kim and G. J. Strimel, “The influence of entrepreneurial mindsets on student design problem-framing,” *IEEE Transactions on Education*, pp. 1-10, 2019.

[12] L. Payne and B. Jesiek, “Enhancing transdisciplinary learning through community-based design projects: Results from a mixed methods study,” *International Journal for Service Learning in Engineering, Humanitarian engineering and Social Entrepreneurship*, vol. 13, no. 1, pp. 1-52, 2018.

[13] J. K. Murray, J. A. Studer, S. R. Daly, S. McKilligan, and C. M. Seifert, "Design by taking perspectives: How engineers explore problems," *Journal of Engineering Education*, vol. 108, no. 2, pp. 248-275, 2019.
[14] J. L. Hess and N. D. Fila, "The manifestation of empathy within design: Findings from a service-learning course," *CoDesign,* vol. 12, no. 1-2, pp. 93-111, 2016.
[15] J. A. Artiles and M. Lande, "Broadening non-designers' solutions for big issues: The education designshop design thinking workshop," *International Journal of Engineering Education*, vol. 32 no. 3B, pp. 1418-1427, 2015.
[16] S. H. Jin, "Collaborative instructional models for teaching community service to engineering students," *International Journal of Engineering Education*, vol. 34, no. 6, pp. 1897-1909, 2018.
[17] S. Jordan and M. Lande, "Additive innovation in design thinking and making," *International Journal of Engineering Education*, vol. 32, no. 3, pp. 1438-1444, 2016.
[18] M. T. Siniawski, S. G. Luca, J. A. Saez, and J. S. Pal, "Design thinking and service learning for first-year engineering students," International Journal of Engineering Education, vol. 32, no. 3, pp. 1508-1513, 2016.
[19] L. Steuer-Dankert, S. K. Gilmartin, C. B. Muller, C. Dungs, S. D. Sheppard, and C. Leicht-scholten, "Expanding engineering limits – A concept for socially responsible education of engineers," *International Journal of Engineering Education,* vol. 35, no. 2, pp. 1-25, 2019.
[20] N. D. Fila, J. L. Hess, S. Purzer, and E. Dringenberg, "Engineering students' utilization of empathy during a non-Immersive conceptual design task," *International Journal of Engineering Education*, vol. 32, no. 3B, pp. 1336-1348, 2016.
[21] S. L. Beckman and M. Barry, "Teaching students problem framing skills with a storytelling metaphor," *International Journal of Engineering Education,* vol. 28, no. 2, pp. 364-373, 2012.
[22] V. Goel and P. Pirolli, "The structure of design problem spaces," *Cognitive Science,* vol. 16, no. 3, pp. 395-429, 1992.
[23] D. H. Jonassen, "Design problem solving," in *Learning to Solve Problems: A Handbook for Designing Problem-Solving Learning Environments*. D. H. Jonassen, Ed. New York, NY: Routledge, 2011, pp. 138-148.
[24] K. Dorst, "The core of 'design thinking' and its application," *Design Studies*, vol. 32, no. 6, pp. 521–532, 2011.
[25] H. A. Simon, "The structure of ill structured problems," *Artificial Intelligence*, vol. 4, no. 3–4, pp. 181–201, 1973.
[26] K. Dorst and N. Cross, "Creativity in the design process: co-evolution of problem-solution," *Design Studies*, vol. 22, no. 5, pp. 425-437, 2001.
[27] G. Stompff, F. Smulders, and L. Henze, "Surprises are the benefits: Reframing in multidisciplinary design teams," *Design Studies*, vol. 47, pp. 187-214, 2016.
[28] J. Kolko, "Abductive thinking and sensemaking: The drivers of design synthesis," *Design Issues*, vol. 26, no. 1, pp. 15-28, 2009.
[29] J. McDonnell, "Design roulette: A close examination of collaborative decision-making in design from the perspective of framing," *Design Studies*, vol. 57, pp. 75–92, 2018.
[30] D. Bairaktarova, W. Z. Bernstein, T. Reid, and K. Ramani, "Beyond surface knowledge: An exploration of how empathic design techniques enhances engineers understanding of

users' needs," *International Journal of Engineering Education*, vol. 32, no. 1, pp. 111-122, 2016.

[31] J. L. Hess, N. D. Fila, and S. Purzer, "The relationship between empathic and innovative tendencies among engineering students," *International Journal of Engineering Education*, vol. 32, no. 3, pp. 1236-1249, 2016.

[32] R. J. R. Blair, "Responding to the emotions of others: Dissociating forms of empathy through the study of typical and psychiatric populations," *Consciousness and Cognition,* vol. 14, pp. 698-718, 2005.

[33] G. Hein and T. Singer, "I feel how you feel but not always: The empathic brain and its modulation," *Current Opinion in Neurobiology,* vol. 18, pp. 153-158, 2008.

[34] Kouprie and F. S. Visser, "A framework for empathy in design: Stepping into and out of the user's life," *Journal of Engineering Design,* vol. 20, no. 5, pp. 437-448, 2009.

[35] A. C. Strauss and J. M. Corbin, *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory. 2nd ed.* Thousand Oaks, CA: Sage, 1998.

[36] J. Saldana, *The Coding Manual for Qualitative Researchers, 2nd ed.* Thousand Oaks, CA: Sage, 2013.