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Design thinking in collaboration with students to identify and address learning challenges in two science and engineering courses

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Abstract

Research in engineering education has called to our attention the need for transformative mindsets and complementary tools for student-centred learning and related teaching opportunities. Despite, or perhaps due to the logical and pragmatic nature of traditional science and engineering approaches, the authors appreciated the opportunity to learn from broader conversations in teaching and learning inquiry and from educators in other disciplines about more meaningful ways to generate a deeper understanding of student learning challenges and how they might be addressed to improve our teaching. In this study, we built on the literature on "design thinking" and "students as partners" as pedagogical approaches to enhance student learning.

The objective of this work was to explore how science and engineering educators can use empathetic design, known in the design space as "design thinking," to engage students in improving their learning. Individual interviews were conducted with students from two courses, a graduate-level engineering course and an undergraduate science course. Participants described their values and motivations in relation to their learning though stories about specific aspects of the course curriculum. An empathy map, a design thinking tool, was used by investigators to analyze each interview, identifying needs and insights about students' engagement in each course. Based on this initial understanding of student learning challenges, researchers generated ideas to improve learning. Participants were then invited to join small focus group discussions to share their feedback and contribute their own ideas on the reimagined learning experience.

From researchers' reflections and collaborative discussions, three themes emerged in relation to fundamental learning problems shared by students across disciplines: students' challenges in allowing themselves to be *vulnerable* – and more specifically, to learn from failure – throughout the learning process, *collaboration* with peers and instructors to achieve understanding (in contrast to a divide and conquer strategy to attain the "correct" final outcome), and, related to each of these, *co-learning* opportunities for students and educators for greater impact on both teaching and learning.

This case study demonstrates the value of engineering and science educators applying design thinking tools and mindsets in collaboration with students as partners in reimagining their teaching and learning experiences.

Introduction

Research in engineering education has called to our attention the need for transformative mindsets and complementary tools for student-centred learning and related teaching opportunities. Engineering and science students need to develop a range of competencies beyond simply technical skills to address the complexity of societal challenges often referred to as "wicked" problems. Recognizing that students in science, technology, engineering, and mathematics (STEM) fields require complementary skills such as communication, collaboration, and creativity to engage meaningfully with stakeholders and address a challenge within a given context is the first step; learning how to effectively teach these skills (i.e., competency-based education) is a wicked problem in and of itself [1], [2].

In addition to effectively integrating learning strategies that support the development of students' competencies, instructors require more effective ways to assess their teaching and improve performance. The assessment process is a means by which to hold teachers and lecturers accountable for learning outcomes, ensuring a quality education system as demonstrated by students having gained the required knowledge and competencies [3], [4].

An effective assessment of student learning should help students develop critical thinking and analysis skills, which traditional assessment tools such as short-term assignments or post-course exams usually fail to deliver. Likewise, current methods of teaching assessment, such as post-course surveys, lack the ability to identify students' deeper learning challenges or understand why experiences were meaningful to them. Furthermore, surveys do not provide an opportunity for students to meaningfully engage in developing their own learning experiences.

Design thinking is an approach to innovation that may be equally applied in the field of engineering (e.g., to address complex challenges like climate change and healthcare) as in our systems of education to identify and attend to student learning challenges [5]–[8]. It is an inherently experiential process in which designers work closely with those for whom they are designing to understand their needs, motivations, and values.

The Hasso Plattner Institute of Design at Stanford University describes five modes of the design thinking process: empathize, define, ideate, prototype and test [9], [10]. Design thinking is used to reframe a challenge from the perspective of the end-user prior to generating and testing ideas through an iterative process. Through abductive reasoning, designers identify insights and opportunities from in-depth qualitative research focussed on social and emotional (human) experience, rather than broad datasets more typical in quantitative research methods.

In the education space, similar empathetic design approaches such as design-based research [11]–[13] have been used to address complex student-centred challenges [8]. The "students as partners" (SaP) model is likewise described as a process to co-create learning and teaching in collaboration with students [14], [15] where partnership is "a specific form of student engagement, with very high levels of active student participation." [16]

Not only can such an empathetic approach be used to gain a deeper understanding of student learning challenges, it is also a framework that creates actionable outcomes in partnership with students (i.e., design, prototype, and test a reimagined experience). For this reason, design thinking was the proposed methodology for instructors to evaluate and improve teaching and learning in collaboration with students.

Objective

The objective of this work was to explore how science and engineering educators can use empathetic design, known in the design space as "design thinking," to engage students in improving their learning. This project was intended to create a case study of a practice-oriented approach to identifying learning challenges.

Methods

Investigators built on the literature on "design thinking" and "students as partners" as pedagogical approaches to enhance student learning. Since two authors teach design thinking based on the frameworks provided by the Stanford d.school and IDEO, a leading design firm, they were able to apply and adapt these methods and tools to address the student learning challenge. The "end-users" for the design challenge were the students from the two courses; the five modes of the design thinking process were completed in several phases as shown in the storyboard in Figure 1. Three investigators conducted and analyzed interviews to *empathize* with the students. They then iteratively *defined* the learning challenges from the student perspective, came up with *ideas* to address their challenges, and generated low-fidelity *prototypes* to describe a reimagined learning experience. These prototypes were *tested* with the same students who participated in the initial interviews as part of focus group sessions for each specfic course. The feedback received from participants was then used to improve prototypes that could be implemented in the classroom.

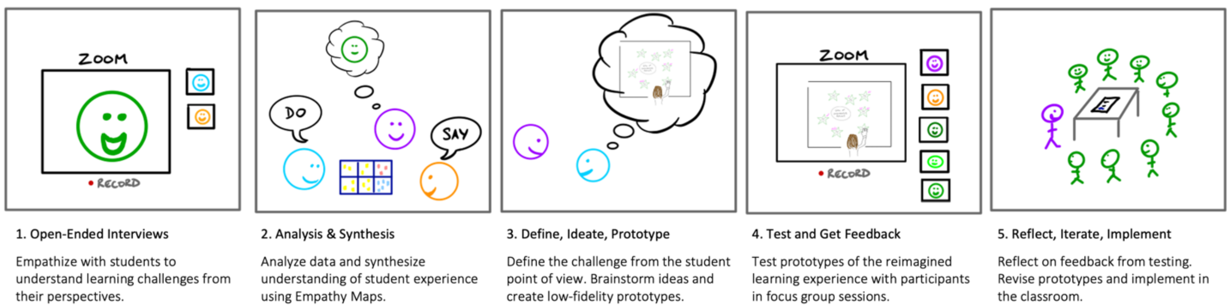

Figure 1: A storyboard illustrates each phase of the research study that used a design thinking approach to identify and address student learning challenges.

The protocol was approved by the McMaster Research Ethics Board.

Participants

Three students who had previously participated or were currently students in an undergraduate science course (biochemistry) and three recent graduates from a Master of Engineering Design program at McMaster University participated in this study. Individual interviews were conducted with each of the six participants all of whom were invited to join one of two focus group sessions later in the study. Five of the six original participants took part in the focus groups; one student from the undergraduate science course did not respond to the invitation.

Individual Interviews

To empathize with students and understand the learning challenges from their perspectives, investigators conducted individual, open-ended interviews with the six participants. Knowing that the researchers' connections to the individual courses may present a conflict to participants, each interviewee was given the option to identify any researcher whom they did not want present at the session. Since no participant made a request with respect to their interviewers, two investigators, including at least one affiliated with the course being discussed, conducted each interview. Interviews were recorded for analysis purposes. Each interview lasted 45–75 minutes and was guided by the following questions:

- When considering the Learning Objectives that your instructor shared with you, what stood out to you as a particularly meaningful learning experience? This could be related to your journey through a course project, a classroom/lab experience, or something more specific.
- Why was it meaningful?
- What was challenging? Why?
- What (if anything) would you change about this experience?
- What would you add/remove/modify?

As part of the empathetic interviewing process, investigators encouraged participants to tell stories about specific learning experiences that revealed their values and motivations by asking follow-up questions, such as "Why did you feel that way?" and "Could you tell me more about that?"

Analysis and Synthesis: Empathy Maps

An empathy map, a design thinking tool, was used by researchers to analyze each interview using Google Jamboard as their virtual collaboration platform. Empathy maps are similar to thematic analysis tools more commonly used in qualitative research to identify important insights emerging from the data. By articulating what interviewees said and did in the left quadrants of the map (e.g., through quotes, body language, and their actions at the time of learning), investigators were able to infer what the students may have been thinking and feeling in the right quadrants of the map. By analyzing what participants said, did, thought, and felt, investigators could then synthesize data to identify students' needs and related insights about their engagement with the learning material in the context of each course.

Define Ideate Prototype

Based on this initial understanding of student learning challenges from the learners' points of view (PoV), the group of researchers generated 'How might we' (HMW) questions which are often used in design thinking to initiate a brainstorming session. The researchers selected the most promising HMWs according to the sense of opportunity conveyed in relation to the most meaningful insights. As a group, the researchers then generated a multitude of ideas by building on one another's contributions addressing one HMW question at a time.

Once the most promising ideas had been selected by the research team, low-fidelity prototypes were generated to convey how the ideas could be integrated into a reimagined learning experience for students. One prototype was created for the biochemistry students' focus group session; separate prototypes were generated for the design students' focus group. Due to time limitations, one investigator designed the initial prototype for the biochemistry students' reimagined experience and received preliminary feedback from the other two researchers. Similarly, only two researchers were available to develop prototypes from the ideas generated using the engineering students' empathy maps and brainstorming sessions.

Test: Focus Groups

Participants who completed the individual interviews were then invited to join small focus group discussions to share their feedback and contribute their own ideas on the prototypes of the reimagined learning experiences. Investigators used the following questions to guide each focus group discussion:

- Based on our individual interviews with you and your peers, we learned about students' needs in the Biochemistry 2L06 / SEP760 course. We have reimagined a student learning experience and would like to get your honest opinions. *FACILITATORS PRESENT THE PROTOTYPE(S) AND OBSERVE INITIAL RESPONSE/REACTION.*
- Is there anything that surprises you? If yes, what?
- Is there anything you expected to find that is not there?
- What is unnecessary if anything?
- If you had a magic wand, what would you change about this experience?

Reflect, Iterate, and Implement

The researchers had an opportunity to reflect individually and debrief as a group following each focus group interview and discussed what was learned. The following questions helped guide researchers' reflections on understanding learning from the student perspective:

- What did I learn about the students' learning experience? How did the experience foster/hinder learning for them?
- What did I learn about the students: their values, mindsets, ways of being?
- What realities of the science/engineering learning environment did I observe?
- What connections can I make between what I learned and my initial knowledge of the
- science/engineering learning environment?
- What surprises or contradictions did I observe in the choices students make?
- Can I identify a common characteristic or trait based on their interview that may foster/hinder their learning?
- What learning problems and opportunities did I observe?
- What insights do I gain by putting my observations in the context of the pedagogical literature I know?

The investigators who are also design thinking instructors considered how the prototypes could be revised and implemented in the course. Learnings about the biochemistry course were shared in a meeting with the course instructor.

Findings and Discussion

Researchers reviewed each interview and contributed to collaborative empathy maps, one for the biochemistry students and another for the engineering design graduates. Figure 2 shows the empathy map for the engineering graduates based on data from the initial individual interviews. Several learning challenges were identified for the students from each of the two courses through an analysis of quotes and behaviours that led to an understanding of needs and insights using the empathy map tool.

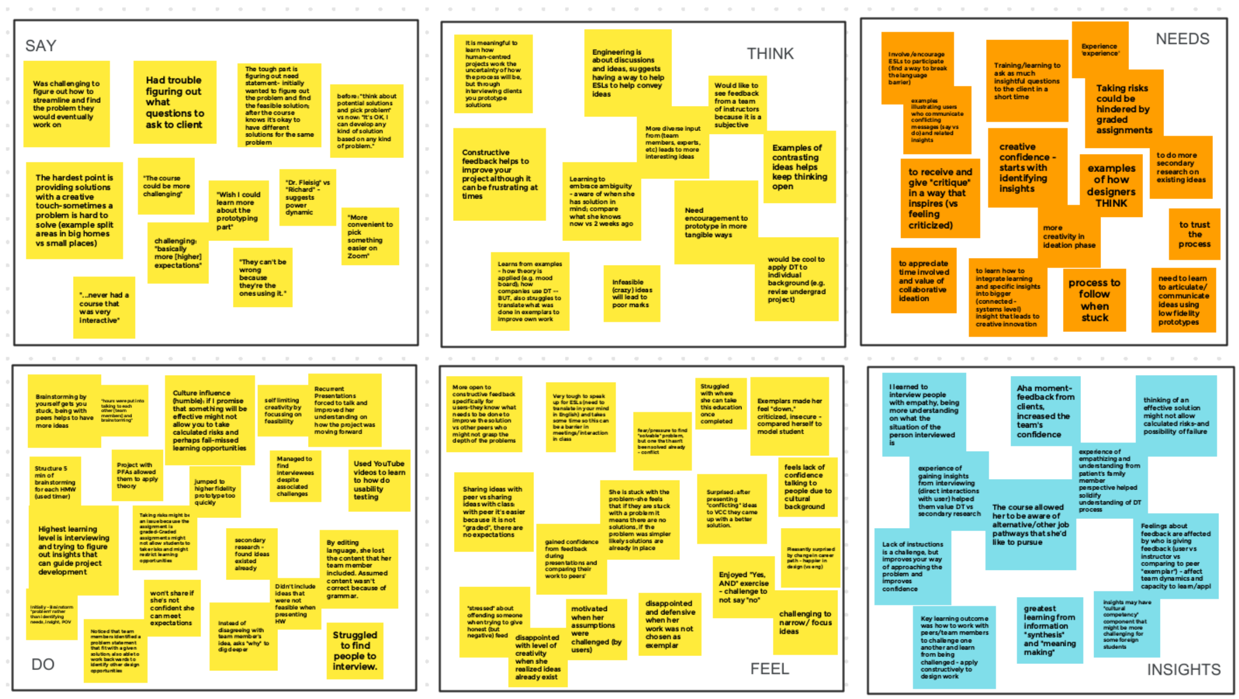

Figure 2 Empathy map created from interview data for the engineering graduates. Yellow notes show data in the Say, Do, Think, *and* Feel *quadrants. Orange and blue notes identify* Needs *and* Insights, *respectively. The figure illustrates the tool used to guide the process and provides an overview of the quantity of data collected and analyzed; individual data elements are not intended to be shown here.*

The researchers chose to focus on the following learning challenges which were considered to have the greatest opportunity for impact: 1) learning from failure, 2) collaboration, and 3) creative confidence. Examples of data from the science students that led to the discovery of learning challenges include: *Say* – "If you didn't get that but your lab member did then we're moving on anyway;" *Do* – Everyone in the class cheered after a student loaded their lab sample; *Think* – Access to peers changed the level of expectation around lab prep: you don't have to prep as much; *Feel* – More comfortable with teamwork, less comfortable with individual work; *Need* – To work independently to make sense of and understand material; *Insight* – 'Divide and conquer' approach is more efficient, while the collegial/ collaborative approach is more effective in terms of learning. Findings from both empathy maps and collaborative researcher discussion are summarized below.

Learning from Failure

Despite students acknowledging that their instructors had encouraged them to make mistakes and learn from failure within both courses, they still indicated that they struggled with this practice. Personal grade requirements, previous training, and their perceptions of the student-instructor relationship contributed to expectations that they achieve "success" in their first attempt at a course task (for example, an experiment works as intended or a design project meets end-user needs). Investigators learned that students' confidence is built through both external validation, such as cheering for mistakes in the biochemistry course, and internal motivation to share their learning with larger audiences.

While certain participants appreciated extra support offered by instructors and teaching assistants, others indicated that too much "handholding" could be detrimental to self-efficacy or reduce opportunities to make the course more challenging if they had higher personal learning goals. Researchers speculated that some students may not make the connection between failure and iteration as an effective learning strategy.

Collaboration

Students are required to work in groups in both courses and at times considered a "divide and conquer" approach to teamwork, in which each team member undertook a separate task, as the most efficient strategy. Investigators identified a need for a cooperative, integrated team approach to learning that would help students make sense of course material together with their peers by benefitting from one another's knowledge and diverse experience.

Creative Confidence

According to David and Tom Kelley of the design firm, IDEO, creative confidence is "the ability to come up with breakthrough ideas, combined with the courage to act." [17] Related to the theme of "learning from failure" investigators noticed that some participants felt criticized when receiving feedback from either an instructor or an end-user on a project or assignment in the engineering design course rather than seeing the opportunity for inspiration and creativity. In both courses, students' confidence was still associated with performance (e.g., grades or comparing their course-related work performance with one another), which could discourage risk-taking and decrease possibilities for creativity.

Based on what researchers learned through their analyses of the individual interviews and empathy maps, they used Point of View (PoV) statements to define the specific learning challenge for each group of participants. How Might We (HMW) questions associated with each PoV were used to launch their brainstorming sessions. PoV statements and HMW questions are commonly used design thinking tools which were expressed as follows for the two design challenges:

Biochemistry students' PoV:

> Students need a way to learn from mistakes and failures during the biochemistry course because they don't take advantage of this opportunity as much as they could despite having a safe, inviting, and caring environment.

HMW

- make learning from failure easier?
- help students identify their own gaps in knowledge and encourage them to fill those gaps?
- teach students and TAs to coach/mentor other students?

Engineering design students' PoV:

> Students need new "safe" ways to experience, make sense of, and embrace design thinking processes to support their *creative confidence* because, the apparent risk associated with these unknown processes leads to "ideation incapacity."

HMW

- experience the value of the connection between empathy and design direction?
- convey the challenging aspect of design when the process seems simple? (e.g., knowledge synthesis – complexity)?
- encourage students to take risks?

Several ideas were generated for each HMW question, and a low-fidelity prototype was created to address the learning challenge for each group of participants based on a combination of the most promising ideas. The prototype presented to the participants from the biochemistry course during the focus group interview was a storyboard (similar in format to Figure 1) describing how a student might engage with failure through various practices of sharing, learning from others, and reflecting on their own experiences. As part of the second focus group session, investigators asked the former engineering design students to participate in two role-play design exercises that could be used in class. In the first exercise, participants were asked to play different roles in a healthcare scenario: physician, family member, hospital administrator, and finally the patient herself. As part of the second exercise participants were instructed to design within certain technical constraints. In both exercises, participants were challenged to question the problem as given and consider how it might be reframed from another perspective. Such divergent thinking supports creative confidence.

The feedback received from participants on the prototypes shared by researchers in the focus group sessions provided additional insights about students' learning. The specific themes and challenges previously identified were related to a fear of vulnerability. Interestingly, participants indicated they would be more comfortable sharing their mistakes and associated learning if it was for the benefit of other students such as the next class cohort. Furthermore, sharing their failures in class requires a low-stakes environment (e.g., anonymity) without any perceived judgment. Participants from the design course were reassured by the realization that they had learned to mitigate common biases in the design process, such as the tendency to jump to the "obvious" solution. They also benefitted from seeing that empathy in the focus group design exercise led to different ideas being generated by their peers which were equally valid and moreover provided a richer perspective of the design challenge. This helped solidify an understanding of the value of learning from and with others (i.e., collaboration).

Applying design thinking to identify *why* an experience was meaningful from students' perspectives provided investigators a deeper understanding of their learning challenges as well as the opportunity to act on that knowledge to improve their teaching. Researchers' reflections on the emerging theme of vulnerability and on the process of empathetic design to reimagine student learning highlighted the effectiveness of instructors *co-learning* with students for greater impact on both teaching and learning. By being vulnerable with students and being curious about their learning experiences, educators not only made it easier for students to be vulnerable with them, but also supported their own creative confidence. Like the students as partners approach, this process engaged students in developing their own course experiences, thereby empowering them to take ownership over their own learning [14], [15], [18].

Conclusion

This case study illustrates the benefits of applying an empathetic design approach (design thinking tools and mindsets) to achieve a deeper understanding of student learning challenges and to address those challenges more effectively in collaboration with students themselves. The design thinking framework allowed investigators to act on their learning about students' motivations, values, and behaviors, specifically by designing, prototyping, and testing ideas *with* learners before simply implementing them in the classroom. The process supported students in contributing to the development of their own learning experiences. By working with students as partners, engineering and science educators can engage in a collaborative, creative process to reimagine teaching and learning experiences.

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