Engineering Students' Beliefs about Decision Making in Capstone Design: A Revised Framework for Types of Informal Reasoning

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Abstract

Engineers engage in design, and design requires decision making. Whether picking a color for a spoon designed to aid a person with physical challenges or choosing the material for the blade of a turbine; engineering design decisions are consequential for the design and how it performs upon implementation. To use a spoon, the person may need to like the color; and the material of the blade must be strong enough for an endurance task. Because design decisions are consequential, undergraduate engineering programs have a responsibility to prepare students as decision makers.

Capstone design courses allow undergraduate engineering students to experience open-ended design projects before starting their professional careers. As such, capstone serves as an opportunity to develop students' ability to make decisions in an ill-structured setting. Typically, explicit instruction related to decision making includes an introduction to rationalistic tools, such as decision matrices or House of Quality. However, in the process of providing rationalistic tools to students, engineering education may be implicitly perpetuating the belief that engineers make decisions through rationalistic reasoning alone. In reality, other types of informal reasoning, such as empathic and intuitive reasoning, are utilized for decision making in ill-structured contexts such as engineering design. The beliefs that undergraduate students hold about decision making in the context of design is not well understood, and this work contributes to this gap in the literature.

To learn more about students' beliefs about decision making, we collected qualitative pilot data in the form of both one-on-one, semi-structured interviews and written reflections from ten engineering students in capstone design courses at a large, Midwestern university. Participants provided accounts of previous decision-making experience within an engineering context. Throughout the data collection, they also were asked to describe how they perceive their own decision making with respect to an initial theoretical framework for types of informal reasoning, which included rationalistic, intuitive and empathic reasoning. Data were analyzed through open and values coding.

This paper presents the resulting shift from our initial, three-part theoretical framework for informal reasoning (rationalistic, intuitive, empathic), to a revised, two-part framework for informal reasoning (logical and intuitive). This decision was based upon both our data analysis process and revisiting extant decision-making literature. The contribution that we provide in our revised framework for studying informal reasoning can be used by engineering educators and researchers to think critically about and investigate their own students' development as decision makers and their approaches to teaching decision making in the context of engineering capstone design. Future work will include data collection utilizing the revised framework and more in-

depth data analysis with respect to students' beliefs about decision making, as well as the influence of a year-long capstone design course on their beliefs.

Key words: Decision making, Reasoning, Capstone design, Beliefs

Introduction & Background

Engineers are widely recognized as problem solvers [1]. Solving problems commonly includes working collaboratively in design teams to generate solutions to real-world problems [2]. Throughout the engineering design process, engineers make decisions about how to understand the problem, design solutions, evaluate solutions, and then implement the solution that best aligns with user needs. Many of the decisions made in the engineering design process have implications for the well-being of members of our society and our globe. As such, undergraduate education should facilitate holistic development of engineering students' ability to make decisions in ill-structured settings such as design [3, 4]. In engineering education, explicit discussion of decision making often focuses on the introduction of rationalistic approaches or tools. However, current decision-making research demonstrates that humans do not make decisions through the use of rationalistic reasoning alone. For example, as people gain knowledge about the rules for how to make decisions and practice the process of making decisions, they start to become proficient in utilizing intuitive reasoning when the situation approaches [5-7]. The disconnect between the reality of human decision making and the formal instruction provided to engineering students is problematic if it leads students to hold incomplete views about engineering decision making (e.g. engineers utilize strictly rationalistic reasoning to make design decisions). However, the beliefs that engineering students actually hold about how engineering decisions are made are not well understood.

Broadly, this work stems from a larger, exploratory project to characterize students' beliefs about different types of informal reasoning in engineering decision making. As a first step, we collected pilot data during the 2018-2019 academic year in order to understand the ways in which students expressed their beliefs about decision making. These data, which included interviews with students and written reflections from the same participants, were analyzed in order to understand the efficacy of our initial framework for studying types of informal reasoning in the context of engineering design. Our findings include a shift from a three-part framework for informal reasoning (rationalistic, intuitive, empathic), to a two-part framework for informal reasoning (logical and intuitive). In the next sections we discuss the role of engineers as decision makers, how decision making has been presented in engineering classrooms, and the reality of decision making with regards to previous investigations.

Engineers as Decision Makers when Solving Complex Problems

Engineers contribute to solving complex problems that occur in our world. Preparing students to make decisions understanding social responsibilities with regards to ethics and sustainability has become an important skill [8, 9]. This is mainly due to the consequences decisions have on a broad variety of stakeholders [10]. Moreover, Nair called for engineering education to prepare students with a larger frame of perspective as key decision makers [4]. These calls to prepare engineering students as key decision makers present the idea that engineering decisions have consequences beyond the engineering industry, and students need to recognize the broader impact of engineering decisions.

Design problems tend to be ill-structured and do not possess a single right answer [5]. As such, engineers must make decisions in contexts that contain ambiguity and uncertainty. Because it is impossible to have all the information known at the time of a design decision, engineering decisions require informal reasoning beyond rationalistic tools. This is formally acknowledged as accredited engineering programs are expected to develop students' ability to use engineering judgment [11]. Preparing engineering students as key decision makers seems to be a relevant calling in engineering education. However, decision making is not a topic well understood and taught in engineering classrooms.

Limitations of Typical Engineering Instruction for Decision Making

Undergraduate engineering students typically enter classes with little to no experience on how to approach the decision-making process for engineering design projects. Due to the inexperience as decision makers, engineering students are instructed to utilize rationalistic and structured methods that enable them to make design decisions, such as converging from conceptual design ideas to a detailed design. For example, in capstone design courses students are often introduced to the Pugh Method (i.e. weighted decision matrix) as a quantitative way to map conceptual designs to user specifications or criteria. Other common tools include using a House of Quality or Strength, Weaknesses, Opportunity, and Threats (SWOT) analysis. Each of these tools are prescriptive—they provide recipe-like strategies for how decisions should be made [5], which are essential for novice engineers in context-free situations [6]. However, the reality is that engineering industry problems are ill-structured and complex, meaning that each situation is embedded in its own context and all the information is not provided [2]. Due to the ill-structured nature of complex problems, rationalistic tools become limited, opening the opportunity to utilize other types of informal reasoning such as intuitive or empathic [12, 13].

Undergraduate engineering curricula rely almost exclusively on introducing students to rationalistic tools for decision making. While these tools are certainly useful for novice decision makers and have a place in engineering decisions, they are incomplete for the reality of engineering practice—all the information cannot be known, and time or resources are constrained [2]. The disconnect between engineering curricula and the reality of engineering industry motivates us to briefly summarize literature from studies that show how people actually make decisions in ill-structured contexts.

Reality of Decision Making in Ill-Structured Contexts

Extensive research has documented that humans make decisions based on more than solely rationalistic decision-making tools. Naturalistic Decision Making (NDM), as a field, has documented the reality of how professionals make decisions in real time, and the results show that they do not use rationalistic processes that simultaneously weigh the pros and cons of multiple options. According to Zsambok and Klein, at the novice stage of decision making, people need guidance and rules. However, as they gain experience and realize the context of each situation, intuitive reasoning is utilized in decision making [6]. Experienced decision makers who work under time pressure utilize mental simulations for decision making. For example, firefighters instead of carefully analyzing pros and cons, they create images of situations in their heads and imagine the consequences of their decisions, going with the first decision that does not seem to have any significantly negative consequences [14]. Similarly, Recognition-Primed Decision (RPD) is a decision-making model where the person approaches the situation by recognizing the scenario and assimilating it to previous experience, which draws on their own experience and which is not objective [15]. Although intuitive reasoning is rarely mentioned explicitly in undergraduate engineering education, it certainly plays a role in engineering decision making. Intuitive reasoning is rooted in knowledge and experience [16]. Sadler-Smith states that intuitive reasoning, when correctly managed, is a useful tool in ill-structured decision making, where time and facts are limited, and several options seem plausible [12]. Further, correctly managed intuitive reasoning is not exclusive from rationalistic reasoning, meaning that intuitive reasoning is influenced by previous situations where rationalistic reasoning was utilized [6, 17].

In addition to using rational and intuitive reasoning, design situations also require empathic reasoning because it is necessary to understand the impact of decisions on stakeholders. IDEO presented empathy in design as “the capacity to step into other people’s shoes, to understand their lives, and start to solve problems from their perspectives” [18, pp. 22]. Krippendorff states that design shifted from being production-centered to human-centered [19]. Additionally, Zhang and Dong state that engineering design should be centered on human needs [20]. These scholars demonstrate the necessity to make engineering design more focused on the stakeholders’ perspective rather than the technical perspectives prioritized by engineers. The utilization of empathic reasoning in engineering decision making can create a bridge between the engineering perspective and the stakeholders’ perspective.

The utilization of both intuitive and empathic reasoning when making decisions is rarely presented explicitly in engineering classrooms. However, decision-making literature demonstrates that in reality, these types of informal reasoning are required for decision making in complex contexts such as design. To guide our study of the beliefs that undergraduate engineering students hold about the role of these different types of reasoning in engineering decisions, we chose an initial framework for types of informal reasoning that included rationalistic, intuitive, and empathic reasoning [21]. While we acknowledged that our target participant population of undergraduate engineering students lack the opportunity to develop intuitive engineering expertise, we chose the initial framework because it was developed based on an empirical study that emerged specifically from undergraduate students making sociotechnical decisions, which like design problems, lack a single correct answer. In the next section, we present the decision-making framework that we originally utilized to investigate undergraduate engineering students' beliefs about decision making.

Initial Framework for Types of Informal Reasoning: Rationalistic, Emotive and Intuitive

In their study of patterns of informal reasoning, Sadler and Zeidler [21] posed sociotechnical decisions to undergraduate students, thoroughly probed for justification to capture their reasoning behind their decision, and then coded the data to empirically develop a framework for the different types of informal reasoning that were used. As science education researchers, they utilized genetic engineering dilemmas in order to solicit the participants' informal reasoning. For example, they asked students if parents should be able to clone their child if they knew the child was going to die. Their analysis resulted in three distinct types of informal reasoning: rationalistic, emotive, and intuitive, as recreated in Figure 1. They define each type as follows: 1) rationalistic reasoning is cognitive, logical and often impersonal, 2) emotive reasoning is also cognitive, but comes from a place of care and is influenced by emotions, and 3) intuitive reasoning is instantaneous and manifests as an inexplicable gut feeling.

In terms of patterns of use for decision making, they found that all students used rationalistic reasoning—it was the most common type of reasoning captured by the interview protocol. The three different types of informal reasoning were often used in conjunction with one another—sometimes they were complimentary (the different types of informal reasoning both supported the same decision), and sometimes they were contradictory (the different types of reasoning supported different decisions). This is represented by the overlap between the circles in the figure.

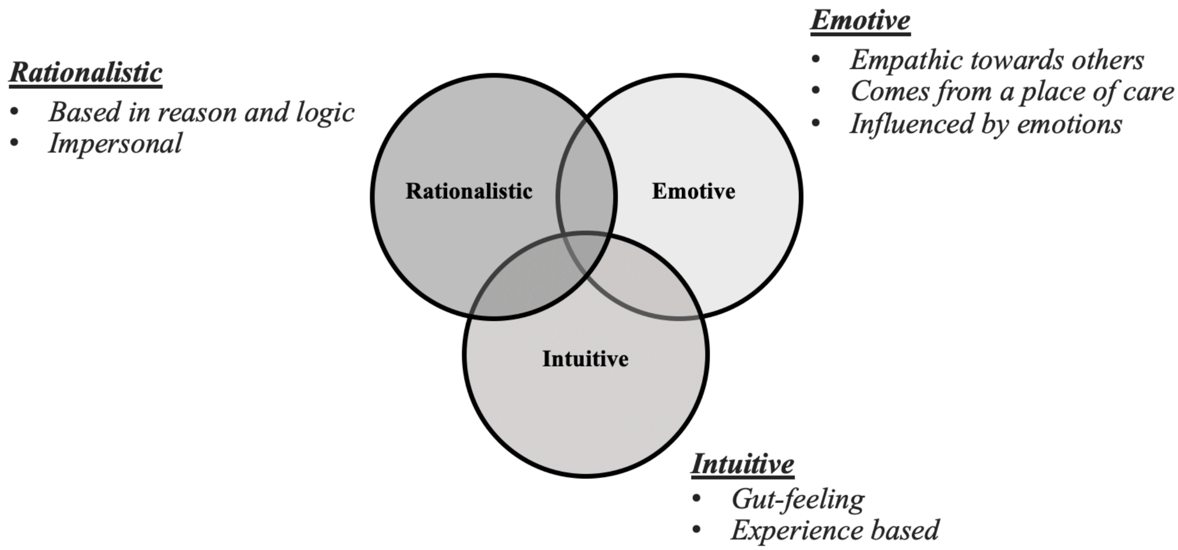

Figure 1. Adapted from Sadler and Zeidler's empirical framework for types of informal reasoning [21].

Research Question

One of our goals during the pilot year of our study was to ensure that this framework would be valid as an effective way to study undergraduate engineering students' beliefs about the types of informal reasoning in decision making in an engineering design context. More explicitly, our research question was as follows: How can the efficacy of the framework developed by Sadler and Zeidler for types of informal reasoning be established or improved in order to study undergraduate engineering students' beliefs about types of informal reasoning in engineering decision making?

Preliminary Revisions to Framework for Informal Reasoning

Before collecting any data to answer this research question, we made a preliminary revision to Sadler and Zeidler's framework by changing the word "emotive" to "empathic." This change was initially sparked during a workshop on this topic presented at Capstone Design conference [22], where the third author (Dringenberg) realized that the word "emotive" was not valid for our purposes as it conveyed the wrong idea. When presented the framework, participants understood "emotive" as emotional without capturing the intended meaning of utilizing empathy when making decisions. We felt justified in making this preliminary revision because, in the original publication of the framework, Sadler and Zeidler explicitly recognize how emotions may be pervasive when making decisions with ethical implications [21]. In fact, we contend that emotions are integrated into our thinking, and therefore they cannot be distinguished from cognition [23-25]. Furthermore, the shift to using the label "empathic" is still in alignment with the authors' original description of this type of reasoning; they defined emotive reasoning as having "feelings of concerns for other individuals' needs," or using empathy [21, pp. 115]. In sum, we feel this change was needed to avoid a false fixation on emotions while still conveying the consideration of multiple perspectives as defined by the original authors, to improve the efficacy of the framework.

Research Approach

Our goal for the broader project in which this contribution is situated is to be able to systematically study the beliefs that undergraduate engineering students hold about the different types of reasoning for making decisions in the context of engineering design. Next, we describe our research approach and the revisions we have made to the initial theoretical framework to improve its efficacy for achieving our research aim. In general, the research consisted of a pilot study conducted during the 2018-2019 academic year, which had the goal of improving the quality of the study design, including the theoretical framework, before replicating the process with more students.

Participants

We recruited students from engineering capstone design courses at a large, public, Midwestern university. At the beginning of the 2018 autumn semester, we announced the opportunity to five different capstone design classes that represented a variety of engineering majors and minors. Through flyers and emails, students were informed about the objective and design of the study, how to participate, and what the compensation would be. Students who were interested completed an electronic survey, where they were prompted to provide demographic information and a brief response to a prompt designed to solicit their beliefs about the role of different types of reasoning when making engineering decisions. Ten undergraduate students completed the survey and were invited to join the study, but only nine completed the full study. These participants represented the following engineering majors: Mechanical Engineering, Chemical Engineering, Biomedical Engineering, and Engineering Science (minor). The participants selected their own pseudonyms, which are used in this paper, in order to maintain confidentiality.

Data Collection

We collected data through one-on-one interviews and written reflections submitted electronically. For this paper, we analyzed the pre-formal decision-making interview (conducted when participants were just starting their capstone design course) and three written reflections from the participants collected at regular intervals throughout the autumn semester of the pilot study. The interviews captured how engineering students experienced and navigated the decision-making process for both a personal decision and an engineering decision. Participants drew on previous experiences such as internships or coursework when describing an engineering decision; they explained the context and process for making their decision. Students were then asked to describe the role they believed each type of reasoning (rationalistic, empathic, and intuitive) played in their decision-making approach. The purpose of the reflection prompts was for participants to describe the on-going decisions they were making in their capstone design teams and to elaborate on their beliefs about the role of the three types of reasoning (rationalistic, empathic, and intuitive) for those decisions throughout the semester. The reflection prompt and interview protocol can be found in Appendix A and B respectively. Participants were compensated with a $20 gift card for their interview and a $10 gift card for each written reflection.

Data Analysis

After collecting interviews and reflection prompts, we analyzed the data. Two members of the research team (Guanes and Thanh) individually coded them utilizing holistic and values coding lenses [26]. Holistic coding focuses on analyzing the data as a whole and identifying themes. Values coding focuses on looking at the data through three different elements (values, attitudes, and beliefs) in order to learn about participants' perspective about, in this case, the types of reasoning in decision making. After each iteration of individual coding, we came together to discuss the codes and emergent patterns identified. During these conversations, we provided our interpretations of what the participants were communicating. Our team also utilized a whiteboard in order to draw what the decision-making process looked like according to the participant and what the process appeared from our perspective. While analyzing the data, we realized there was a mismatch between our use of the theoretical framework to solicit data and the ways in which participants described their decision-making approaches and beliefs. Consequently, this prompted us to revisit the literature and, ultimately, revise the framework and its efficacy for our study to address our research question.

Findings to Inform Modifications to Theoretical Framework

In this section, we present the two major findings from students' responses during our pilot study that led us to make changes to our theoretical framework for types of reasoning used in engineering decision making. First, we realized that students tended to describe rationalistic decision processes in ways that, based on the initial framework, we would code as empathic reasoning. This situation demonstrated to us the close relationship between empathic and rationalistic reasoning. Second, we found that students associated intuitive reasoning with previous experience and that the initial framework did not solicit their experience when their decisions were based on guesses. The sections below provide evidence for our findings.

Finding 1: Empathic Reasoning and Rationalistic Reasoning are Closely Related

After reading the first set of students' responses to our reflection prompts, one of our noteworthy findings was how students portrayed empathic reasoning. When students were prompted to provide the role of rationalistic reasoning in their decision, they would describe what the initial framework defined as empathic reasoning (taking into consideration a stakeholder's perspective). The quotes below, from Darcy and Carlton, demonstrate the types of situations that students would describe as utilizing rationalistic reasoning:

> *"We made our decision based on rationalistic problem solving. We outlined our options and considered both what would be most advantageous to the user's rehabilitation as*

well as what would be the most efficient way to finish our [CAD software] model in a timely fashion." – Darcy

"The team used lots of rationalistic thinking and logic to evaluate the designs based on the needs' criteria. This includes, but was not limited to, the specific features of the design and how those aspects would impact the occupant in a realistic real-life scenario, assessments of the complexity of technology as applied to a specific set baseline, and outside knowledge and experience used to assess the impact of specific design features on criteria." – Carlton

These quotes from students show how they are aware their decisions will affect the user. However, they see this aspect of their decision-making process as rationalistic rather than empathic reasoning due to the way it occurs in their design teams. As Carlton explained, empathic reasoning is embedded within the rationalistic decision-making tools that the participants were taught in their capstone design courses. These responses led us to think that in order to improve the efficacy of the framework for our research purposes, empathic and rationalistic reasoning should not be separated in our framework. Empathic decisions are done similarly to rationalistic decisions, in the fact that they are both slow and conscious types of reasoning. We concluded that the efficacy of the framework could be improved, specifically to study beliefs about decisions in an engineering context, by grouping these two types of informal reasoning together.

Finding 2: Intuitive Reasoning Informed by Experience or as a Guess

Our data analysis also revealed that when prompted to discuss the role of intuitive reasoning, students indeed talked about situations that we would code as utilizing intuitive reasoning. However, they talked more specifically about intuitive reasoning as a type of informal reasoning that is based on experience. For example, Isabella mentions that when brainstorming ideas of seat designs, she intuitively thought of her previous experience sitting in desk chairs herself and the characteristics that made it seem comfortable:

"Intuitively I decided to brainstorm these three ergonomic principles. I thought about seats that I found comfortable and why they were more comfortable than other seats. For example, I thought immediately of my desk chair and decided that lumbar support was a key part of comfort due to the shape of our spines." – Isabella

This finding led us to realize that students' previous experience informs their intuitive reasoning. Students' previous experience become a gut-feeling when a similar context is presented. In a similar case, Brian states that when deciding what stirring equipment to buy for their project, he thought of his own experience and how it would make others feel:

> *"Intuitive reasoning—my past experience with the equipment played a large role here. In the past, having to stir mixtures by hand was not fun. So, I had an instinct that it would not be any better now."* – Brian

Moreover, Isabella mentions the importance of having experience in order to utilize her intuitive reasoning when making decisions:

> *"If this [specific material] wouldn't make this turn into a bone I would be like 'I don't know, I guess I'll look it up.' Um, that's not something that I can think of… Um, I think now, if I were given the same problem after the experience I've had, I think it would come a lot faster to me."* – Isabella

Through these responses, we were able to realize that students describe their use of intuitive reasoning as times when they were able to draw on their previous experience. These students were also aware that technical intuitive reasoning requires experience in engineering-related decision making, which they acknowledge they may not have yet:

> *"Having so little experience in situations like this, I more rely upon rational queues than intuitive queues just because I didn't really have any reference point for a decision like this. Since it being my first internship, there wasn't a whole lot of experience I could create a gut feeling for."* – Carlton

Finally, with respect to intuitive reasoning, we observed that the initial framework did not provide the opportunity to describe instances where students may have gone with their initial gut feeling that was not based on experience, but instead on a guess. For example, a participant in our study felt that he could not complete the reflection prompt due to the way his team approached the decision-making process. According to him, the decision they made was a guess and did not fit any of the types of reasoning provided by us (rationalistic, empathic, and intuitive). These finding led us to think of ways that we could improve the efficacy of the framework by allowing students to talk about the use of intuitive reasoning when based on previous experience and on guess.

Modified Theoretical Framework for Types of Reasoning

After analyzing the data and realizing the two findings presented above, we concluded that the initial theoretical framework needed modifications to improve its efficacy for studying students' beliefs about the use of the types of reasoning when making decisions in the context of engineering capstone design. We decided to revisit decision-making literature with the aim of connecting our findings to extant literature before finalizing our modifications. As a result, we modified the framework by 1) combining empathic and rationalistic reasoning as two distinct subgroups of logical reasoning (slow and conscious) 2) keeping intuitive reasoning as its own type of informal reasoning, but breaking it into two distinct subgroups including intuition based on experience and guess, and 3) linking empathic and rationalistic reasoning as informing the subgroup of intuitive reasoning that is based on experience. The resulting modified framework is shown in Figure 2.

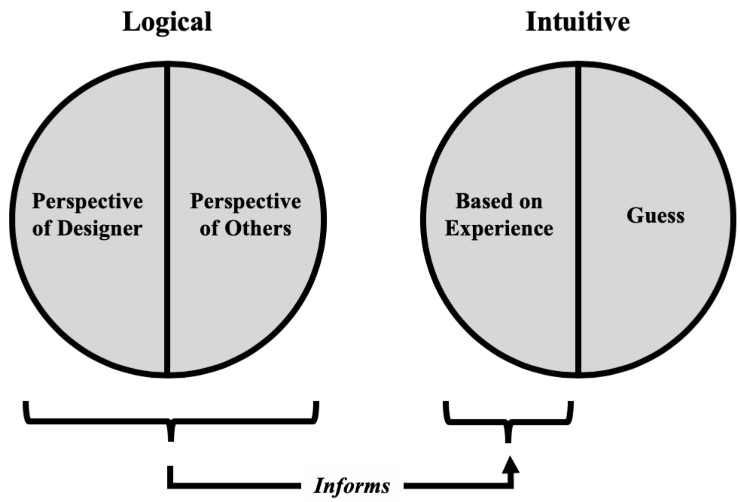

Figure 2. Modified framework for types of reasoning to study beliefs about decision making in the context of engineering capstone design.

Support for Modifications from Extant Literature

This section provides a more detailed explanation of how extant literature supports our revised framework. In general, we see alignment between our modified framework and the well-established research demonstrating dual-system thinking, such as the concept of thinking fast (System 1) and thinking slow (System 2), popularized by Kahneman [17, 27]. Kahneman describes System 1 as our immediate reactions to situations based on our previous experience. These reactions are intuitive and automatically prompted, stemming from peoples' subconscious. On the other hand, System 2 is conscious, slow thinking, which requires effort and attention.

Modification 1: Rationalistic and Empathic Reasoning as Subgroups of Logical Reasoning

Labeling the left half of our framework as "Logical" reflects the established concept of System 2 as the slow, effortful and conscious process used in decision making. In the modified framework, rationalistic and empathic reasoning have been reconceptualized as two subgroups of "Logical" reasoning: "Perspective of Designer" or "Perspective of Others." An example of "Perspective of Designer" would be a student describing their own interpretation of using an engineering tool, such as Finite Element Analysis, in order to make a decision about what type of material to use for a structure. This replaces the category of "rationalistic" in the initial framework. "Perspectives of others" would be captured by students describing their effort to consider how the design would affect stakeholders. This replaces the category of "empathic" in the initial framework. Placing "Perspective of Others" as a subcategory of slow, effortful reasoning aligns with the authors of the initial framework; Sadler and Zeidler documented that students guided their decision-making process by consciously considering the perspective of others when making decisions [21]. This may or may not be influenced by emotions, but it is still a conscious and slow process just like rationalistic reasoning. These modifications fall from Finding 1 described above.

Modification 2: Intuitive Reasoning as Based on Experience or as a Guess

Maintaining the second half of the framework as “Intuitive” reflects the established concept of System 1, which is defined as automatic and immediate processing. Significant research has made a distinction of intuition as a qualitatively different process than conscious, cognitive reasoning [28, 29]. Additional literature argues that intuitive reasoning is a part of all decisions [30]. However, others make the distinction between intuition that is equivalent to valuable expertise [31, 32] and intuition that is fallible as it relies on heuristics and bias [33]. In other words, intuition may be “shallow,” or just a guess [34]. To align with our second research finding and these examples from prior research, we decided to break intuitive reasoning into two subgroups: “Based on Experience” and “Guess.” These represent “Intuitive” in the initial framework but now they allow for us to distinguish the source of the intuitive reasoning.

Modification 3: Intuitive Reasoning Informed by Logical Reasoning

The third change made to the framework demonstrates how “Intuitive” reasoning is influenced by previous experience (not just a guess). Our conscious, slow thinking informs our fast thinking as we make decisions in situations in which we have previous experience [17]. For example, expert decision makers can often understand the context of the situation and estimate what will be more beneficial based upon their intuitive reasoning [6]. Similarly, our participants mentioned that their previous experience influenced their intuitive reasoning when making decisions. The arrow in Figure 2 reflects this modification.

Limitations

Our work has three major limitations. First, the data collected is based on what students are able to express in terms of their beliefs about the forms of reasoning in engineering decision making. This is a limitation because intuition, by nature, is not something that can always be understood consciously. Second, the data was collected from just nine engineering undergraduates at a single university, which limits our ability to ensure efficacy of the modified framework for investigating beliefs about decision making in engineering more broadly. Third, participants were limited to a subset of engineering majors: Mechanical Engineering, Chemical Engineering, Biomedical Engineering, and Engineering Science (minor). Beliefs about decision making in students from other majors, such as Computer Science, might look different than the ones we had represented in our participants, as teaching practices and cultural differences exist between engineering disciplines.

Conclusion and Future Work

Decision making is a complex and interdisciplinary topic with significant implications for engineering education and beyond. There is a disconnect between the reality of engineering practice and what is being taught in the classroom setting with respect to decision making. Our ongoing goal is to study the beliefs that engineering students in undergraduate engineering design education hold about the different types of reasoning in order to make instruction around engineering decision making more inclusive and realistic. No frameworks exist for studying this in our specific context, and our pilot study revealed that the framework that we initially selected from extant work required modification for our purposes.

Through this work, we improved the efficacy of the framework by making modifications including 1) framing rationalistic and empathic reasoning as two subgroups of a more general category of logical reasoning, 2) framing intuitive reasoning as including two subgroups representing reasoning based on experience or as just a guess, and 3) acknowledging the role that logical reasoning plays in the development of intuitive reasoning that draws on experience.

We encourage engineering instructors in engineering design education to provide students with the opportunity to learn explicitly about this model for types of reasoning that may be utilized in engineering decisions, and in which situations they each are useful. Moreover, it is essential to help them distinguish the difference between intuitive reasoning based on experience and mere guess. The contribution of this paper will be utilized in our future work while interviewing more engineering students enrolled in capstone design to understand their beliefs about the types of reasoning when making decisions.

Appendix A

Written Reflection Prompt

1. Please, provide your name.
2. First, provide an overall summary of a recent decision you made in your engineering design team. Follow these steps to craft your response:
    - Describe the situation
    - Describe the options that you were choosing between
    - Explain how you went about making the decision (tools you may have utilized, such as pros and cons list)
    - Describe why the decision made was the best option for the project
    - Mention who was involved in the decision-making process
    - Describe how you felt about the decision
    - Provide details on what you were thinking and doing that helped you make the decision.

Definitions of each form of reasoning:

Rational—deliberate, uses logic to weigh pros and cons, often impersonal
Example: comparing the cost or time needed for different options

Intuitive—an immediate reaction to one of the options, gut-feeling, not easy to explain
Example: having an immediate feeling that one of the choices is good or bad

Empathic—considering the decision from another person's perspective
Example: considering the needs of the user, or maybe someone else on your design team

3. Second, please describe what role each form of reasoning played in your decision making (definitions and examples are provided above).
4. Finally, based on your experience in Capstone Design so far, describe how you think engineers should make decisions <u>and why</u>.

Appendix B

Pre-Formal Decision-Making Instruction Interview Protocol

We are interested in hearing about a decision that occurred when 1) ***you needed to make an <u>explicit</u> choice between <u>multiple possible options</u>****, and 2)* ***<u>the choice had implications</u> or mattered to your project****.*

1. Tell me a little bit about yourself. What's your major? Are you part of any design team? Have you had an internship?
2. Tell me about an important decision that you've made in an engineering context. What were the alternatives? What did you choose and why?
    a. What was the timeline like?
    b. Who was involved?
    c. How did you reason through the decision? Why? Pros? Cons?
    d. How did you feel about the decision once you made it?
3. Tell me about an important decision that you've made recently in your life. What were the alternatives? What did you choose and why?
    a. What was the timeline like?
    b. Who was involved?
    c. How did you reason through the decision? Why? Pros? Cons?
    d. How did you feel about the decision once you made it?
4. There are different ways to reason through decisions. I'm going to ask you to talk about the decisions you just described with respect to three distinct aspects of human reasoning: rational, intuitive, empathy.
    a. First, rational. This type is deliberate, uses logic to weigh pros and cons, often impersonal. What role did rational reasoning play?
    b. Second, intuitive. This is an immediate reaction to one of the options, gut-feeling, and is not easy to explain. What role did intuitive reasoning play?
    c. Finally, empathy. This type of reasoning considers the decision from another person's perspective. What role did empathic reasoning play?
5. Overall, how do you think engineering/life decisions should be made? Why do you think that? Where does that belief come from?
6. So far, what has engineering education taught you about how to make decisions?
7. Do you have anything else you'd like to share with respect to decision making?

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