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AN EXPLORATION OF THE ROLE OF EMPATHY IN ENGINEERING DESIGN EDUCATION

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ABSTRACT

Empathy is a potentially impactful part of the design process because it can help engineers relate to the end user by identifying what and why certain experiences are meaningful. Because of this, the design community has been invested in devising and assessing empathic design activities. These efforts align with the recent push to transform engineering education from having a sole focus on technical skill development to the creation of 'holistic engineering education.' This approach emphasizes the development of engineers who are able to engage with a broad range of stakeholders, understand different cultural expectations, and develop affective disposition skills. While there have been some recent efforts to identify interventions that *could* impact empathic tendencies in engineering design, there is limited evidence on how students' empathy develops over the course of an engineering class project and what factors impact this development. Additionally, research on empathy has been primarily limited to individuals, meaning we do not know how it impacts team performance, particularly during concept generation and selection. This is problematic because teamwork is an essential component of engineering education due to its ability to promote problem solving and improve the exploration of the solution space. However, without an understanding of the role of team empathy in design, it is unclear when or how to intervene in engineering education to create empathic teams.

In order to fill these research voids, the main objective of this dissertation was to identify the factors that contribute to the building or waning of empathy in engineering design education and the subsequent impact on engineering design performance. Specifically, this dissertation aimed to: (1) explore the development of students' empathy development, and the underlying impact of the design and educational context on that development, (2) understand the relationship between student empathy and design outcomes, and (3) investigate the impact of the empathic composition of teams on design outcomes. This was accomplished through an experimental study with more than 100 students in four sections of a first-year design course and a computational simulation study of more than 10,000 teams.

The results from this dissertation highlight that students' trait empathy and empathic self-efficacy did not increase across the design project and the context of the design problem did not

have an impact on students' empathy development. Interviews with the course instructors identified several constraints in the applications of empathy building-activities in an engineering design project. The insights throughout this dissertation urge design education researchers to not rely *solely* on students' perceptions of their empathy since the results from this dissertation found that students' perceptions of their empathy development did not align with the empirical results.

A more detailed analysis of students' activities during concept generation and selection revealed that empathy might be useful in different ways during different design stages. When devising pedagogical interventions in engineering education, this dissertation suggests that interventions geared toward increasing empathic concern are favorable during concept generation while the design community should refrain from evoking personal distress during concept generation. Meanwhile, during concept selection, the findings recommend triggering perspective-taking tendencies to allow designers to select elegant ideas.

Finally, this dissertation provides recommendations for composing teams in engineering design education. Specifically, the findings from this dissertation call for the importance of identifying which outcome (overall creativity, elegance, usefulness, uniqueness) is desired, and thus encourage instructors to compose teams based on the empathic tendency (fantasy, personal distress, perspective-taking, and empathic concern) these outcomes are impacted by. This dissertation highlights the complicated nature of empathy in design and call against a one-size-fits-all view of empathy in design, and hence urge engineering educators to compose teams and design interventions based on the results presented in this dissertation.

Taken as a whole, this dissertation presents one of the first and most extensive empirical investigations aimed at formalizing the role of empathy in engineering design education. The pursuit of such a formalization is critical given the need for soon-to-graduate engineering students to engage with a broad range of stakeholders in their future careers. Without understanding *when* or *how* to prepare those graduating engineers to be empathic in engineering education, the graduating engineering workforce could fail to understand the needs of diverse users and subsequently fail in solving those users' problems.

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Finally, I am writing these words while the world is fighting the novel coronavirus (COVID-19). I would like to deliver my prayers, thoughts, and empathy with all of humanity in these unprecedented times.

CHAPTER 1

INTRODUCTION

Doug Dietz, an industrial designer of one of the most technically advanced multimillion-dollar magnetic resonance imaging (MRI) machines, admits that he “failed at his job” when he observed just how petrified end users - children - were of his machine [1]; nearly 80% of all pediatric patients needed to be sedated to be scanned [2]. In response to this, Doug turned his focus to using empathic experiences, including visits to daycare and pediatric centers, to redesign his machine into the “Adventure Series” scanner, which included calming decorations and playful themes [3]. This costly redesign drove patient satisfaction scores up to 92%, significantly reduced the number of sedated patients to fewer than 27% of patients, and increased patient throughput on the machine [2, 4].

This example illustrates the importance of empathy, or “the reactions of one individual to the observed experiences of another” ([5], p. 113), in the early conceptual stages of the design process (i.e., problem definition, concept generation, and selection [6]) [7]. In these stages, empathy development allows designers to “relate to [the user] and understand the situations and why certain experiences are meaningful to these [users]” (p. 67, [8]). If empathy is not developed early in the design process, there may be a mismatch between the final design and the requirements of the end user [9], ultimately leading to costly redesign efforts [10].

From an educational perspective, recent research has identified a potential relationship between empathic design experiences (e.g., simulating visually impaired scenarios) and engineering students’ ability to generate creative ideas [11-13]. Additionally, students’ perceptions of the relevance of their coursework in impacting the world have been shown to increase with empathic experiences, such as involving students in the use of a wheelchair [14]. These examples align with the recent push to transform engineering education from having a sole focus on technical skill development to the creation of ‘holistic engineering education’

[15-17]. This approach emphasizes the development of engineers who can engage with a broad range of stakeholders [15], understand different cultural expectations [16], and develop affective disposition skills [17]. This is particularly important in engineering design education because designers often design for people who are unlike themselves and must understand the needs of those diverse users [18, 19] to subsequently solve their problems [11, 12]. While there have been some recent efforts to identify the factors that impact empathic tendencies in engineering design, such as having a personal connection to the population being studied [20] and participating in simulated empathic scenarios [13] during short-form workshops, there is limited evidence on how a student's empathy develops over the course of an engineering class project or what factors impact this development. Without this knowledge, we do not know when or how to intervene in engineering education to create empathic engineers.

Currently, the engineering design literature provides conflicting interpretations of the role of empathy in the concept generation stage of the design process. For instance, Genco et al. [12] and Johnson et al. [11] found that simulating empathy-evoking scenarios helped designers generate ideas that are of high quality [12], novelty [11], and variety [11]. However, other researchers have identified a dark side to empathy, empathic vampirism [21, 22], where designers' empathy would allow them to over-identify with the end users, resulting in designing for themselves [21]. While prior research has explored the varying roles of empathy in concept generation, the role of empathy in driving creative concept *selection* has been scarcely researched. This is problematic since generating creative ideas does not necessarily guarantee the final design's creativity [23, 24], as the "availability of creative ideas is a necessary but insufficient condition for innovation" ([25], p. 48). Clarifying the role of empathy during the concept selection stage is critical due to the importance of the concept selection stage in driving successful engineering design [26-28].

Additionally, research on empathy has been primarily limited to individuals, meaning we do not know how empathy impacts team performance. This is problematic because teamwork is an essential component of engineering design [29-31] due to its ability to promote problem solving [32] and improve the exploration of the solution space [33-35]. As such, investigating the impact of *team empathy* on engineering design outcomes is warranted. Specifically, it is unknown how the empathic composition of teams (average and standard deviation of team members' empathy [36]) would impact design outcomes in the earlier stages (i.e., concept generation and selection [6]) of the design process. Formalizing the role of team empathy in the earlier stages of the design process is important because the success and final cost of a product can be linked to the early conceptual stages of the idea's emergence [10, 37], and being empathic in those stages *could* be the gateway to creative solutions to a design problem [7]. However, without clarifying the role of team empathy in design, it is unknown if, when, and how empathy is important in promoting creative design outcomes.

1.1 Dissertation Goals

In light of this prior work, the goal of the dissertation was to identify the factors that contribute to the building or waning of empathy in engineering design education and the subsequent impact on engineering design performance. Specifically, the following three research objectives were addressed:

Research Goal 1. Explore the development of students' empathy development and the underlying impact of the design and educational context on that development.

Research Goal 2. Understand the relationship between student empathy and design outcomes.

Research Goal 3. Investigate the impact of the empathic composition of teams on design outcomes.

The remainder of this chapter discusses the expected contributions of this work and the outline of this dissertation document.

1.2 Expected Contributions

The results of this dissertation contribute fundamental knowledge on the role of empathy in engineering design education and can inform interventions geared at empathy development in several ways. First, this dissertation provides some of the first evidence on the transitive nature of empathy in engineering education and formalizes the impact of the design context and course instructor on students' empathy development. Second, the dissertation deepens the understanding of the impact of trait empathy on creative concept generation and selection. Finally, the dissertation identifies empathic composition guidelines for design teams in order to drive creative design outcomes in engineering education. Taken as a whole, this dissertation presents one of the first and most extensive empirical investigations aimed at formalizing the role of empathy in engineering design education. The pursuit of such a formalization is critical, given the need for those graduating engineers to engage with a broad range of stakeholders. Without understanding *when* or *how* to prepare those graduating engineers to be empathic in engineering education, the graduating engineering workforce could fail to understand the needs of diverse users and subsequently fail in solving those users' problems.

1.3 Document Outline

The remainder of this dissertation document describes the methodologies, results, and contributions of this dissertation work. Specifically, Chapter 2 presents a synthesis of the existing literature on empathy in engineering design. Chapter 3 presents the overarching research methodology of the dissertation that summarizes the data collection procedure that serves as the foundation for the methodology for the remaining chapters. Chapter 4 presents the work based on the first journal article of this dissertation, which focuses on exploring the development of students' empathy development and the underlying impact of the design and educational context on that development. Chapter 5 presents the work based on the second journal article manuscript of this dissertation, which focuses on clarifying the role of trait empathy in creative concept generation and selection in an engineering design student project. Chapter 6 presents the work based on the third journal article manuscript of this dissertation, which focuses on investigating the impact of the empathic composition of teams on creative design outcomes. Chapter 7 presents a preliminary analysis of future work that starts to investigate the cognitive composition that could lead to more empathic design teams. Finally, Chapter 8 provides a summary of the findings of this dissertation and highlights the contributions and the implications of these findings for engineering design education.

1.4 Summary of Dissertation Papers

To answer the research objectives identified in section 1.1, as outlined in chapter 3, an empirical study was conducted with 103 first-year engineering studies at the Pennsylvania State University to explore empathy development and its role of creative concept generation and selection. The same data set was used to conduct a computational simulation of 13,482 teams in order to examine the role of team empathy. Figure 1.1 provides a summary of the factors investigated in the three papers that constitute this dissertation, and the following subsections provide a brief overview of those three papers.

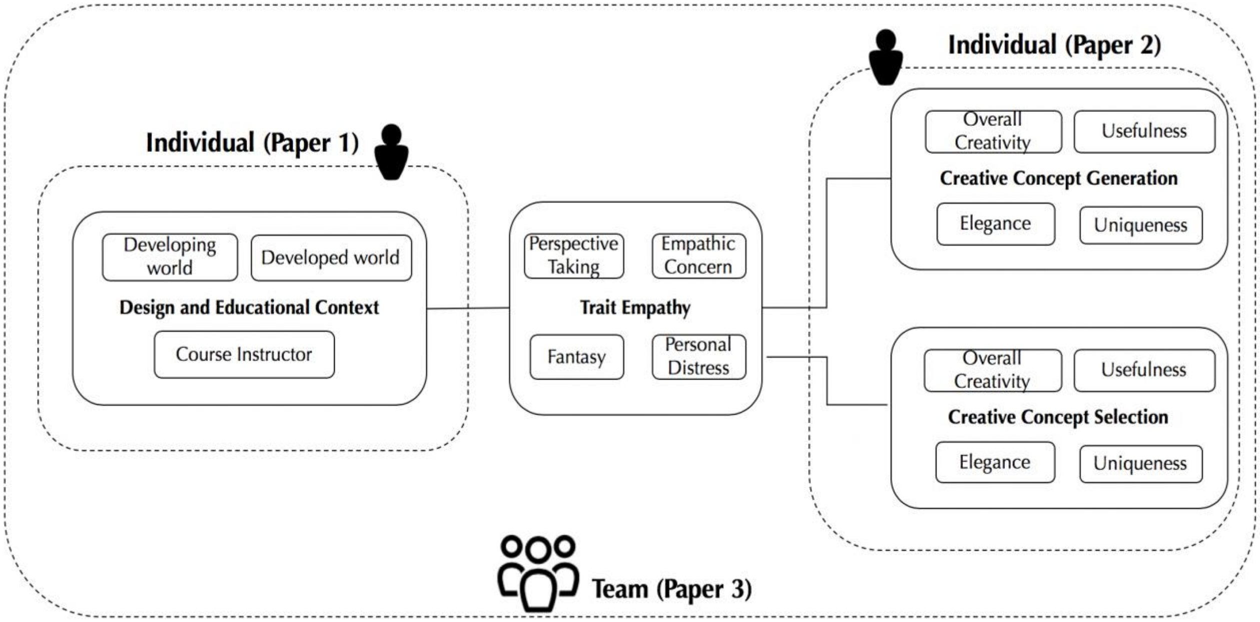

Figure 1.1 Summary of the factors investigated in the three papers of the dissertation

Paper I: Are you feeling me? An exploration of empathy development in engineering design education

The first objective of this dissertation was to explore the development of students' empathy development and the underlying impact of the design and educational context on that development. Thus, Chapter 4 of this dissertation presents work based on a manuscript submitted for publication in the Journal of Mechanical Design. Specifically, this paper summarizes a longitudinal study that explored the development of students' trait empathy and empathic self-efficacy and identified the underlying impact of the design project's context and course instructor on that development. The results from this study highlighted that students' trait empathy and empathic self-efficacy did not increase across the design stages, and the context of the design problem did not impact students' empathy development. Meanwhile, students displayed lower empathic self-efficacy in one of the course sections, and interviews with the course instructors identified several constraints in the applications of empathy building-activities in an engineering design project. Finally, the insights from Paper I urge design education researchers to not rely *solely* on students' perceptions of their empathy when devising or assessing empathic activities in the engineering classroom since the results from this paper found that students' perceptions of their empathy development did not align with the empirical results.

Paper II: Empathy versus creativity? Can trait empathy predict creative concept generation and selection?

The second objective of this dissertation was to understand the relationship between student empathy and design outcomes. As such, Chapter 5 of this dissertation is based on a manuscript to be submitted to the Design Computing and Cognition Special Issue of the Artificial Intelligence for Engineering Design, Analysis, and Manufacturing Journal. The main goal of this paper was to identify the role of trait empathy in creative concept generation and selection in an engineering design student project. The results from this chapter highlight the positive relationship between empathic concern tendencies and the generation of ideas and the negative relationship between personal distress tendencies impacted and idea generation. In addition, during concept selection, perspective-taking tendencies were shown to positively impact participants' propensity for selecting elegant ideas. These results indicated that interventions geared at empathic concern tendencies are favorable during concept generation while the design community should refrain from evoking personal distress tendencies during concept generation. Meanwhile, during concept selection, the findings from this dissertation suggest the value of triggering perspective-taking tendencies to allow designers to select elegant ideas.

Paper III: Can design teams be empathically creative? A simulation-based investigation on the role of team empathy on concept generation and selection

The final goal of this dissertation was to investigate the impact of the empathic composition of teams on creative design outcomes. As such, Chapter 6 of this dissertation is based on a manuscript to be submitted to the Journal of Mechanical Design. The findings from this work are the result of a computational simulation of 13,482 teams of noninteracting brainstorming individuals generated by a statistical bootstrapping technique drawing upon a design repository of 806 ideas. These results call for the importance of identifying which outcome (overall creativity, elegance, usefulness, uniqueness) is desired, and thus compose teams based on the empathic tendency (fantasy, personal distress, perspective-taking, and empathic concern) these outcomes are impacted by. In this paper, we highlight the complicated nature of empathy in design and call against a one-size fits all view of empathy in design. Taken as a whole, the findings from this paper direct engineering educators to identify which empathy tendency is desired and thus compose teams and design interventions based on the results presented in the paper.

CHAPTER **2**

LITERATURE REVIEW

In order to establish the framework for the current investigation, this chapter highlights prior work on (1) assessing empathy development in engineering education, (2) the impact of the educational and design context on empathy development, (3) the role of empathy in engineering design, and (4) teams and simulation studies in engineering design that serve as the basis for the current study.

2.1 Assessing empathy development in engineering education

In order to lay the foundation for this dissertation, it was critical that we survey the literature on current assessment techniques of empathy development in engineering education. While prior research has explored the role of empathy in the engineering classroom [11-13], we still know very little about how students' empathy develops across engineering design projects. This is because most research on empathy in engineering education has been conducted as a component of short-form workshops where researchers examine students involved in an engineering design task for a short period of time (e.g., one classroom period) [15] and not across a larger design project. Conducting such *in situ* research in engineering classrooms could better capture the different activities involved in a design project [38] and provide more meaningful insights on the factors that can lead or dissuade engineering students from developing empathy.

Additionally, most of the research to date has relied on students' *perceptions* of their empathy [15]. Relying on students' *perceptions* of their empathy might be misleading since students might be biased to say they were empathic due to their self-serving bias [39] or social desirability bias [40] where students' attempt to create a favorable image of themselves [40] by marking more attributions for their empathy development [41-43]. One way to overcome this bias is measuring the empathic *tendencies* of individuals [44, 45], a quality that allows for the understanding of the emotions, circumstances, and needs of others [46], and their empathic self-efficacy, their perceived ability to understand others [13, 20].

When assessing an individual's trait empathy, the psychology literature asserts the need to assess both the cognitive component and an affective component [47]. The cognitive component identifies one's empathy as being dependent on the situation, while the affective component identifies empathy as an emotional response and feeling [47]. Hess and Fila [33] have argued that both components are needed to help designers better understand end user needs. Davis' [48] approach to measuring trait empathy has been adopted in the literature because it is one of the few measures that encompasses both the cognitive and affective components of empathy [47]. Specifically, Davis [48] defines four empathic tendencies including: (1) perspective taking, which measures the ability "to adopt the perspectives of other people and see things from their point of view (p. 2, [48]); (2) fantasy, which measures "the tendency to transpose themselves imaginatively into the feelings and actions of fictitious characters in books, movies, and plays" (p. 12, [48]); (3) empathic concern, which measures "the degree to which the respondent experiences feelings of warmth, compassion and concern for the observed individual" (p. 12, [48]) and (4) personal distress, which measures an "individual's own feelings of fear, apprehension, and discomfort at witnessing the negative experiences of others" (p. 12, [48]). Figure 2.1 summarizes a model proposed by Hess and Fila [49] that summarize the cognitive and affective processes that are involved in Davis' empathic tendencies [48]. While these four empathic tendencies shape the cognitive and affective components of empathy [47], Davis stresses the importance of distinguishing between the interpretation of each of the subscales. For instance, personal distress tendencies were found to be negatively related to the three other empathic tendencies and have been found to be related to empathic over-arousal [50], emotional vulnerability [51], anxiety [51], and negative affect [52].

While a recent paper by Surma-Aho, Björklund, and Hölttä-Otto [53] also utilized the IRI in engineering education, their study only reported data on perspective-taking tendencies and specifically addressed a population of *graduate* engineering students. The current works extend that of Surma-Aho et al. [53] by studying the other three IRI empathic tendencies (fantasy, personal distress, and empathic concern) in addition to studying an individual's empathic self-efficacy, their perceived ability to understand and design for the end user [13, 20], across each of the design stages in an undergraduate engineering design project.

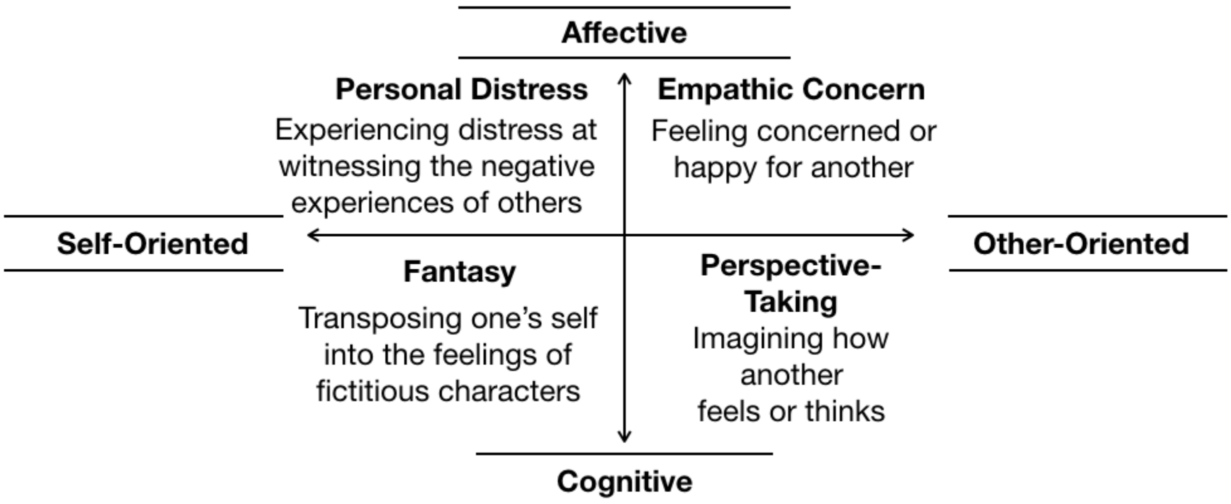

Figure 2.1 A summary of the cognitive and affective processes involved in the four IRI subscales. The definitions are derived from Davis (1980).

2.2 The impact of the educational and design context on empathy development

In order to thoroughly explore trait empathy in engineering education, we first need to explore environmental factors that can impact it in the engineering classroom. These environmental factors include but are not limited to the academic institution [54], the engineering discipline [55], the curriculum [55], the course instructor [56], and the design context [57, 58]. Figure 2.2 provides a summary of the factors that could impact empathy development in an engineering classroom and highlights the two factors this dissertation sought to investigate.

One of the factors that we focus on in the current dissertation is the context of the design problem being used in engineering course projects [57, 58]. In engineering design courses, instructors often *choose* a project from a library of open-ended design problems that have been developed for various contexts (e.g., industry-sponsored [59], humanitarian design problems [60]). Exploring the impact of engineering design project contexts on trait empathy is important

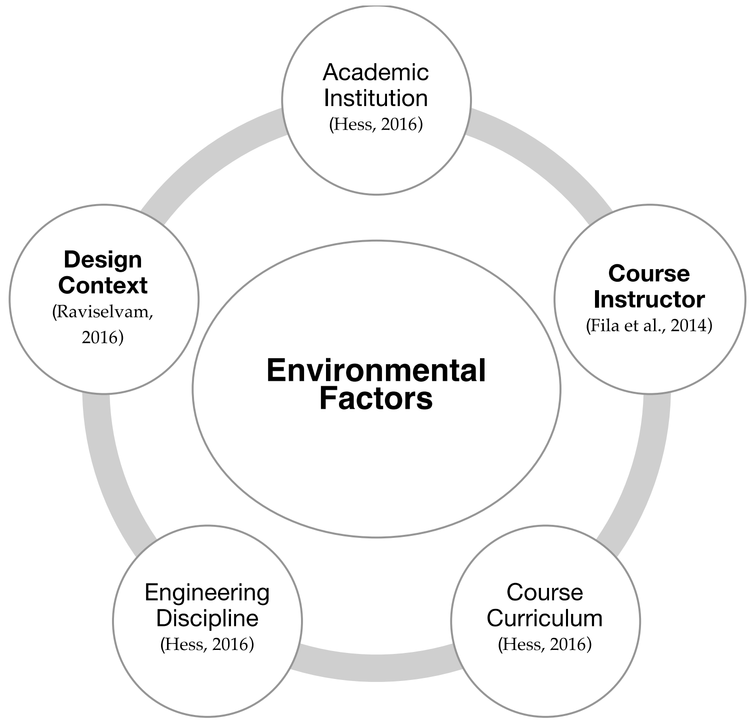

Figure 2.2 Environmental factors that could impact empathy development in an engineering classroom; bolded items are the focus of the current dissertation

because the characteristics of these design projects (e.g., design context) can impact students' empathy development. For example, humanitarian engineering projects, which are becoming increasingly common in engineering design education [61-64], may present a larger challenge for students to understand the culture and context of an end user who is often very different from themselves [65-67]. In fact, a significant number of humanitarian engineering projects in the developing world have failed [66], due to the challenges engineers faced when designing for the developing world [66, 68]. Based on a systematic analysis of failure reports from Engineers without Borders, Mattson, and Wood [66] articulated several pitfalls to designing for the developing world, including the lack of contextual knowledge, the false assumption of user needs as being fulfilled, and the failure to acknowledge that communities evolve over time and between visits. Most of those challenges relate to the engineers' failure in understanding the context rather than the mechanics of the solution-finding processes [65], such as difficulties in language, culture, context, and large geographical distances [69]. Meanwhile, developed world contexts could also help students develop empathy since prior work by Raviselvam [20] found that a designer's personal connection with the end user helped them develop empathic self-efficacy in a short-form workshop [20]. While engineering educators have been utilizing humanitarian engineering projects in their classrooms as a means of developing empathy [49, 70], there is no evidence to date that displays the effectiveness of these projects in developing engineering students' trait empathy or whether the context of such projects impacts students' empathy.

In addition to the problem context, the course instructor may also impact students' empathy development. For example, while some engineering educators identify empathy as a core component of engineering design education [56], other engineering faculty members consider empathy to be an "unnecessary addition" to the engineering curriculum [71] and often minimize the role of empathy in some aspects of engineering [72]. While this prior literature highlighted the perceptions of faculty members on empathy in engineering [71], it did not assess the impact of faculty on students' empathy development.

While prior research in engineering design has attempted to identify the factors that influence designers' empathic tendencies, such as participating in simulated empathic scenarios [13] during short-form workshops and having a personal connection to the population being studied [20], little is known on how the course instructor or design context impact students' empathy development, which this dissertation investigated. This knowledge would better inform engineering educators of the factors that would promote or hinder empathy development in engineering design education. Without understanding the factors that lead or dissuade those graduating engineers to be empathic in engineering education, the graduating engineering workforce could fail to understand the needs of diverse users and subsequently fail in solving those users' problems.

2.3 The role of empathy in engineering design

While the previous section reviewed the impact of the educational and design context in impacting empathy development, it was also important to review the literature on the role of empathy in the design process to understand *if*, *when*, or *how* empathy is critical in the design process. Over the past decade, the design community has become invested in studying empathy [20, 53, 56, 71, 73, 74], due to the role of empathy in helping designers better understand the needs of users that are different from themselves [18, 19], as well as developing a deeper understanding of a design problem [75]. Through semi-structured interviews with engineering students, Fila and Hess [55] found empathy to be related to effective teamwork, problem contextualization, human-centered design, and individual design inspiration. While empathy has been established as an essential component of design [20, 53, 56, 71, 73, 74], the effect of empathy on concept generation and selection is still unclear. Studying the relationship between empathy and creativity is critical since creativity and innovation have been emphasized as necessary facets of design thinking in engineering education [57, 76-79].

Research in engineering design provides contradictory explanations on the impact of empathy in the concept generation stage of the design process. Using design effectiveness measures, researchers have found that empathic design experiences, a five-step design approach that encouraged designers to employ their empathy towards the end user [12], helped designers generate ideas that are of high quality [12], novelty [11], and variety [11]. When compared to briefing student designers on a scenario, simulating extraordinary user scenarios on visually impaired users improved designers' empathic self-efficacy, their perceived ability to understand and design for the end user [20]. Similarly, Rijn et al. [80] explored the influence of watching a video on the end user to develop designers' empathy for children with autism. By videotaping and transcribing the team conversations throughout a one-hour design challenge, they found that the time spent on discussing facts about the users was related to coming up with designs that better fit the users' needs, as assessed by five caregivers to autistic children.

Meanwhile, other research has found that empathy could impede designers from coming up with creative solutions to the design problem. For example, Mattelmäki, Vaajakallio, and Koskinen [81] warn designers about the "empathy trap" [81], where the designers' "attempt to be empathic might articulate popular reflections instead of innovating more radical futures" ([81], p. 73). This can be somewhat analogous to design fixation, or the "blind and sometimes counter-productive adherence to a set of ideas or concepts limiting the output of conceptual design," ([82], p. 4), that has been found to limit the solution space explored by designers [83]. Similarly, Chung and Joo [84] found that designers' engagement with an empathic instruction task (watching a video clip about the end-user) harmed their concept evaluation scores. This impact of empathy has been framed as a "dark" side to empathy [22, 84], or empathic vampirism [21], where the empathizer (i.e., the designer) would over-empathize with the end-user without having their best interests in mind, by seeing the experiences of the end-user as a medium of their own experiences [21].

While recent research explored the impact of empathy in concept *generation*, little is known about the impact of empathy on concept selection. Studying the relationship between empathy and creative design outcomes *solely* during concept generation is limiting, as generating creative ideas does not necessarily guarantee the final design's creativity [23, 24]. Indeed, research has identified that decision-making biases can impact designers' preferences for creativity during concept selection [85, 86], and thus research on the relationship between empathy and creativity during both concept generation and selection is warranted.

Additionally, research has found that a designer's creativity and empathy during the concept generation stage varies based on the designer's personal connection with the end-user [20] as well as the nature of the design task [87]. For example, Starkey, Toh, and Miller [87] reported that the design problem impacted the novelty and quality of the designs generated by student designers. Similarly, Hess and Fila [49] found that the context of the design problem impacted the empathic techniques utilized by designers in the design process. This line of research highlighted the role of the design problem in impacting empathy and creativity, which this work controlled for.

Taken as a whole, prior research in engineering design provides a conflicting discussion on the role of empathy in design processes. Therefore, this dissertation investigated the role of empathy in the concept generation and selection stages of the design process to understand if, when, and how empathy is important in the design process.

2.4 Teams and simulation studies in engineering design

While the previous section discussed the role of empathy in engineering design, most of this prior work has focused on *individual* designers. This is problematic because design activities are typically deployed in teams [29-31], as teamwork promotes promote peer learning [88], problem solving [32], and improves the exploration of the solution space [33-35]. Studying teams is important in the context of empathy research because prior research has primarily related empathy with team performance in a business setting [89]. For example, in a study of senior multimedia students, empathy was found to be a critical component of successful teams as higher levels of empathy enabled students to deter conflict and establish team harmony [90]. Meanwhile, in a study on 97 organizational teams, high empathic concern was negatively related to productivity [91]. Finally, in engineering design, empathy was perceived by engineering students as being a stimulant for team social harmony [55]. While the role of empathy has been studied in terms of influencing successful team outcomes [55, 89-91], the role of the empathic nature of team members in the concept generation and selection stages of the design process has been scarcely studied in engineering design research. Without this knowledge, it is not known if, when, or how *team* empathy is important in promoting design outcomes.

One way of measuring the empathic nature of the teams is through their empathy elevation, the average empathy level of the team, and empathy diversity [36], the standard deviation in teams' empathy. Computing the average and standard deviation of individual attributes to represent team-level constructs is typical in personality research (e.g., [36], [92] and [93]), and has been utilized in previous research in engineering design [94]. While the empathic nature of teams could be modeled with team empathy elevation and diversity, there is no research to date that empirically assesses the empathy elevation and diversity of teams in relation to design outcomes.

On a team level, diversity in personality attributes been used as a factor to form teams in engineering design for the purposes of driving innovation [95], productivity [96, 97], and leadership [98, 99], but n*ot* empathy. By measuring team personality elevation and team personality diversity [36], Neuman, Wagner, and Christiansen concluded that teams with diverse personalities performed better on tasks on an unmanned aerial vehicle control system [95]. On the same line of research, Sook Kim et al. [100] found that diversity, in terms of team members' creative modes, positively impacted team cohesiveness. In terms of cognitive style diversity [101], Menold and Jablokow [102] found that cognitive style diversity helped student design teams explore the solution space. In the context of empathy, prior research has reported that diversity could be a mediator to empathic behavior in social settings [103]. In engineering design, Wong, Sorris, and Siddique [104] claim that empathy is a precursor to an inclusive and diverse environment in engineering design. While that body of research suggests a linkage between diversity and empathy, it has not empirically studied the relationship between team empathy and personality diversity, or diversity in risk-taking attitudes.

One of the challenges of conducting research in teams is the potential cost and time associated with such experimental studies [105, 106]. Because of such challenges, engineering design researchers have turned their attention to utilizing computational simulations of problem-solving teams in lieu of user studies [105-109]. In these simulation-based studies, researchers often model nominal groups [106-108]. In nominal groups, individuals work independently and pool their solutions together near task completion. In brainstorming, this means that individuals first come up with their own ideas rather than generate them as a group [110-113]. This method has been shown to help foster input from all team members [110-114], and increase productivity [114, 115], particularly during the concept generation [116]. In engineering design, the nominal group technique has been shown to be more effective in producing novel ideas than traditional brainstorming methods [117]. When compared to facilitated group brainstorming, Oxley et al. [118] found that student designers brainstorming in nominal groups can generate as many ideas as the students utilizing the facilitated group brainstorming technique while both techniques are superior to the interactive brainstorming technique. In support of nominal groups, Paulus and Dzindolet [115] found that nominal groups, composed of four individuals, are four times as productive as interactive groups, also composed of four individuals.

Since nominal groups involve non-interacting individuals [110-113], engineering design researchers have used datasets from human subject studies of individuals to computationally simulate a large set of nominal teams [105-108] without bearing the costs and efforts of large sample size [105, 106]. In these simulations, researchers combine different combinations of all individuals to get every combination with replacement [108, 109]. This technique closely relates to the statistical bootstrapping technique, a technique that involves "re-sampling the data with replacement many times to get an empirical estimate of the entire sampling distribution" ([119], p. 1). This method has been employed by Wright [120] to create nominal groups in a prior study. These computational simulations have been found to be successful in emulating human team behavior [108].

Some of the limitations of these simulation-based studies are that team members might not be aware of their team membership since the simulation does not account for social effects (e.g., social loafing [114], free-riding [121], etc.) and might fail to capture the context and dynamics of teams [122]. However, prior research successfully implemented the use of nominal teams of problem-solving individuals in engineering design and validated the simulation study results with a representative population [108]. While this type of simulation-based research on nominal teams provides a clear means to studying the performance of engineering design teams [105-108], it is still unknown how the empathic composition of design teams impacts concept generation and selection. Therefore, this paper studied the role of the empathic nature of teams on design outcomes during concept generation and selection.

2.5 Summary of Areas for Investigation

While the prior work synthesized in this chapter underscores the importance of empathy in engineering and the factors that lead students to be more empathic, many studies have relied on students' perceptions of their empathy, and not their trait empathy, and most were conducted as controlled experimental workshops. Indeed, very few studies empirically assess students' trait empathy and the factors that would lead to its development in engineering design education. The research opportunities identified from the literature review can be summarized in Table 2.1. Therefore, the main objective of this dissertation was to identify the factors that contribute to the building or waning of empathy in engineering design education and the subsequent impact on engineering design performance. Specifically, this dissertation aimed to (1) explore the development of students' empathy development and the underlying impact of the design and educational context on that development, (2) understand the relationship between student empathy and design outcomes, and (3) investigate the impact of the empathic composition of teams on design outcomes.

Table 2.1 Summary of the literature on empathy in engineering and the proposed work

Paper	Topic	Undergraduate Engineering Population?	Sample	Sample Size	Metric for measuring empathy	Metric for measuring ideation effectiveness
(Eysenck et al., 1985)	Personality	No	Mixed-age subjects	1,320 (Male = 559, Female = 761)	I_6 Impulsiveness questionnaire	-
(Watson et al., 1984)		No	Undergraduate psychology students	160 (Male = 60, Female = 100)	(1) Hogan Empathy Scale (2) Mehrabian & Epstein Scale (3) Smith Empathy Personality	-
(Ogawa et al., 2018)	Risk-taking	No	Japanese undergraduate students	60 (Male = 34, Female = 26)	Interpersonal Reactivity Index (IRI)	-
(Shu et al., 2017)		No	Undergraduate psychology students	47 (Male = 18, Female = 29)	General Empathy Scale	-
(Todd & Shapira, 1974)		No	US and British mixed-age (18-55)	152 (Male = 76, Female = 76)	Hogan's Empathy Scale	-
(Litchfield et al., 2014)	Design Context	Yes	Engineering undergraduate students	566 (Male = 308, Female = 197)	Community service attitudes (connectedness, empathy, intentions)	-
(Norman Reese)	Educational Context	No	Engineering faculty	7 faculty members	Qualitative (Interviews)	-
(Strobel et al., 2013)		No	Practicing engineers	348 (Male = 292, Female = 56)	Qualitative study (interview)	-
(Carlozzi et al., 1995)	Ideation effectiveness	No	Graduate students in education and psychology	56	Affective Sensitivity Scale	Statement of Past Creative Activities (Bull & Davis, 1980)
(Genco et al., 2011)		Yes	Senior engineering students	46	Did not measure empathy	Quantity, Variety and Novelty (Shah, Vargas-Hernandez, & Smith, 2003)
(Raviselvam et al., 2016)		Yes	Mixed-Age Population at Singapore University	81 (Male = 32, Female = 49)	Empathic Self-Efficacy	Quantity, Variety and Novelty (Shah et al., 2003)
(D. G. Johnson et al., 2014)		Yes	Senior engineering students	177	Did not measure empathy	Originality and technical feasibility (Charyton, Jagacinski, & Merrill, 2008)
Paper 1	Design and Educational Context	Yes	First-year engineering students	N = 103	1. IRI Empathic Self-Efficacy (2 questions)	-
Paper 2	Ideation Effectiveness	Yes	First-year engineering students	N = 103	1. IRI Empathic Self-Efficacy (2 questions)	Consensual Assessment Technique
Paper 3	Teams and Empathy	Yes	First-year engineering students	N = 103	1. Team IRI Elevation (average) 2. Team IRI Diversity (standard deviation)	

CHAPTER 3

RESEARCH METHODOLOGY

In order to set the stage for the three manuscripts developed as part of this dissertation, it is first important to provide an overview of the research methodology of this dissertation. A longitudinal study was conducted with 103 first-year engineering students in four sections of an introduction to engineering design course at the Pennsylvania State University. The data from this empirical study was used for all three papers that constitute this dissertation.

Specifically, throughout the eight-week project, students completed a set of surveys, including but not limited to, surveys that assess their trait empathy. The results from these surveys were used in all three papers, see Figure 3.1. Additionally, students were involved in a concept generation and concept screening activity during the Spring 2019 semester. The ideas generated by students were rated by experts in Fall 2019, and the analysis of these ratings constitute Paper II of the study. Finally, the resulting dataset of survey results and creativity ratings were used to computationally simulate 13,482 teams in order to examine the empathic composition of teams and their relation to creative design outcomes. The results of this simulation were used in Paper III. The remainder

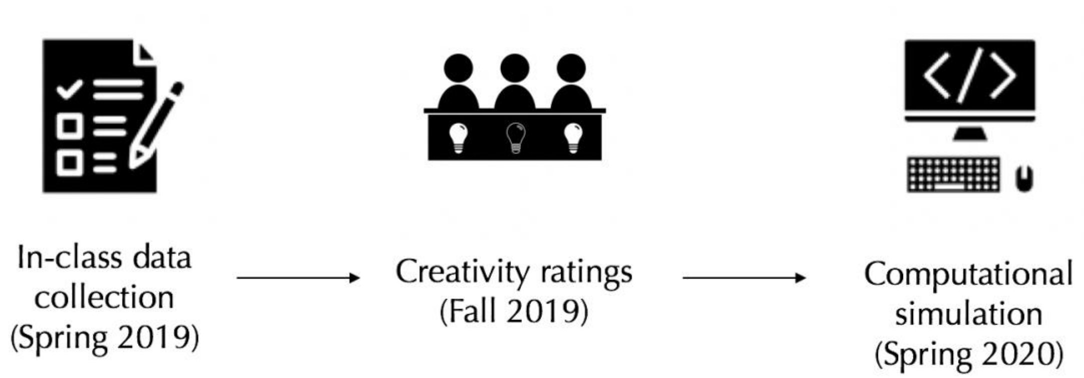

Figure 3.1 Summary of the methodological approach taken in this dissertation

of this section outlines the data collection and simulation procedure that was sought to attain these three papers.

3.1 Participants

Participants were recruited from four sections of a first-year undergraduate engineering design course at the Pennsylvania State University. The first-year course used in the study was an introductory course that gave students the opportunity to go through an in-depth 8-week design project. This course was selected since it provides a cornerstone design experience that encourages students "to identify affected stakeholders and their needs, and incorporate those needs into the project description and design goals" (p.3, [70]). In a paper describing the course outcomes of this design course, Meisel et al. [70] report that design projects in this course should include user groups that students might not be as familiar with (e.g., different cultural background) to help students develop a broader perspective on engineering design challenges. In this course, students are encouraged to consider extreme users and less familiar user groups as a means of developing empathy for those user groups [70]. Notably, this first-year course has received national awards due to its ability to successfully incorporate team-based projects [70, 123]. In all, 103 students (73 men and 30 women) participated in the study.

3.2 Data Collection Procedure

The study was completed over the course of an 8-week design project that included the following design stages: (1) Introduction to the Design Process and Team Formation, (2) Problem Formulation and Customer Needs Assessment, (3) Idea Generation, (4) Concept Selection, (5) Detailed Design, Manufacturing & Prototyping, and (6) Final Design.

At the start of the semester, the researchers presented the study to each of the four sections of the course according to the Institutional Review Board guidelines set forth at the university.

Participation in the study was voluntary, and informed consent was gathered prior to the start of the study. The study then proceeded over the course of nine weeks, see Figure 3.2.

After consent was attained, the participants completed a survey that included: (1) Demographics (Gender and Nationality), (2) Trait Empathy, and (3) Empathic Self-Efficacy, see Data Collection Instruments for a detailed description. The participants were then divided into teams of 3-4 members design teams by the course instructor in their respective sections and were assigned an eight-week project that focused on addressing the United Nation's Sustainable Development Goal 3 (SDG3) [124], which aims at "ensuring healthy lives and promoting well-being for all at all ages." Specifically, they were asked to select between the following challenges: (1) lack of safe water, sanitation, and hygiene services, (2) access to hepatitis-B vaccinations, (3) indoor and ambient air pollution, and (4) road traffic injuries [125]. While the participants in all four sections of the course were allowed to select from these four design challenges, the design context of these challenges varied across the sections [125]. Specifically, two of the sections focused on designing for the *developed* world while the remaining two sections were tasked with designing for the *developing* world, see Table 3.1 for experimental design and [126] for details on the problem statements.

Table 3.1 Breakdown of experimental setup

Section	Design Context	Instructor	Number of participants
1	Developed World	A	18
2		A	32
3	Developing World	B	23
4		C	30

For example, the first design problem for the developed world was: "*A major risk factor for infectious diseases and mortality is the lack of safe water, sanitation, and hygiene (WASH)* *services. How can we, as engineering designers, prevent such incidents from happening by increasing access to or improving the quality of WASH services for the people of the United States? Think of the Penn State University Park campus as an example."* While the first design problem for the developing world was: "*A major risk factor for infectious diseases and mortality is the lack of safe water, sanitation, and hygiene (WASH) services, which disproportionately affects sub-Saharan Africa and Central/Southern Asia. Death rates owing to the lack of WASH services in those two regions were 46 and 23 per 100,000 people, respectively, compared to 12 per 100,000 people globally in 2012. How can we, as engineering designers, increase access to or improve the quality of WASH services in these geographic locations?*"

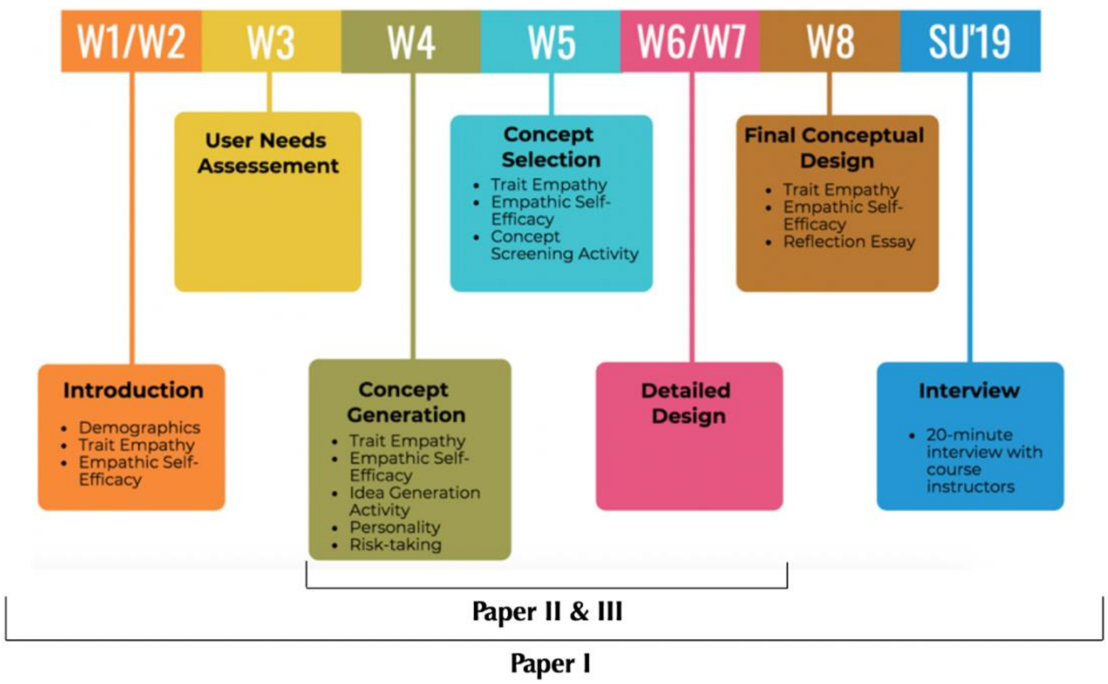

Figure 3.2 Timeline of the project (W stands for a week). The data from weeks 1-8 and Summer 2019 was used in Paper I while the data from Weeks 4-5 was used in Papers II and II

The participants then continued to work on the project per the timeline presented in Figure 3.2. In week 1, students *individually* completed an extreme user research activity where they were encouraged to use reputable online sources to report as much information about their researched user group in a 1-2-page memo. In week 2, students completed an empathy map [127] as a team by using the information they gathered in their user research. Specifically, the design teams were encouraged to answer the following questions: (1) what does the user say, (2) what does your user think, (3) how does your user act, and (4) how does your user feel? From the responses in the empathy maps, teams were then asked to develop personas for their intended user. To further encourage teams to consider their users' needs, teams were asked to formulate point-of-view statements [128]. Next, students were tasked with creating a journey map that can help them visualize key moments in the daily life of the user [129]. Throughout those activities, students were encouraged to consider the user's point of view.

During weeks 3-4, the participants were asked to generate a set of customer needs and conduct an external benchmarking with existing products on the market during. During the concept generation stage (week 4), participants were involved in two ideation sessions: reverse ideation [130], where they were given 15 minutes to come up with *bad* ideas that would make the problem worse, and then individual ideation where they were asked to generate concepts for 20 minutes. During the concept selection stage (week 5), participants were asked to select concepts using a concept screening matrix. Finally, during prototyping and detailed design, the design teams were asked to recall *both* the customer needs and engineering specifications for their projects and consider methods to test their prototype to see if it meets those customer needs. Since the project is a user-centered project, students were instructed to look over the list of customer needs at all stages of the design project, including the final week, where design teams were expected to report their final conceptual design in a written report.

Of importance to the current dissertation, participants were asked to complete the same Trait Empathy and Empathic Self-Efficacy completed in week 1 of the study at the end of week 4, the end of week 5, and the beginning of week 9. They were also asked to complete a 30-item survey assessing their risk-taking attitudes (Domain Specific Risk-Taking Scale) and a shortened personality test (120-item) as homework assignments in week 5 as well. While there is a conflicting discussion in the literature on whether empathy is malleable versus fixed [131, 132], previous research has identified that trait empathy can develop over a short period of time (i.e., weeks) [133]. The activities in each stage of the design process each might require a different cognitive skillset [6, 94, 134, 135] and thus might affect students' empathy differently. Thus, participants' empathy has been surveyed across the four design stages. To avoid experimental biases (e.g., hypothesis awareness [136]) throughout the survey data collection, we do not explicitly use the word empathy in the classroom instruction or in any of the survey materials. Notably, the surveys have not been labeled with the name of the scales [136].

In the week following the completion of the design project, a member of the research team gave a lecture to all four course sections on the importance of empathy in engineering design. During this interactive session, students were involved in an activity on the challenges of humanitarian engineering design problems, where students were asked to analyze failure reports published by Engineers without Borders [137]. Next, students were involved in team discussions discussing the potential role of empathy in various design contexts (e.g., smartphone design, furniture design). Additionally, students were given a lecture on the different definitions of empathy and were engaged in a discussion of the cognitive and affective aspects of empathy and the four empathic tendencies (perspective-taking, fantasy, personal distress, and empathic concern) that constitute Davis' interpersonal reactivity index [48]. After the 75-minute interactive lecture, students were asked to submit a 1-page single spaced reflection essay that was due Friday of that week. The following instructions were provided to students:

> *Please write a 1-page, single-spaced reflection on how your empathy developed over the 8 week-project. Specifically, answer **ALL** of the below questions:*
>
> 1. *How do you feel your empathy developed over the eight-week project? Has it increased? Has it decreased? Why?*
> 2. *Do you think that having empathy is important for your success in the project? Why or why not?*
> 3. *Did you use your empathy to help you come up with more effective ideas to solve the design problem? Please explain with specific examples.*
> 4. *What factors did you consider in selecting a design concept? Did your empathy impact your selection of ideas during concept selection, or in the detailed design stage? Please explain with specific examples.*
>
> *In your reflection, you should reflect on how your empathy developed over the semester and how you, or your teammates, used empathy to design for the end-user. In your reflection, you should draw specific examples from what you did during the project, and also connect to your life outside of class.*

Finally, to better understand the educational context, the three instructors were interviewed after the course ended. The main goal of the interview was to understand how the different in-class activities impacted students' empathy development during the 8-week project. The interview protocol is attached in Appendix A.

3.3 Data Collection Instruments

In order to explore the factors critical to achieving the research objectives, the following instruments were used. Table 3.2 summarizes the instruments used, and the remainder of the section describes the instruments and any relevant calculations used.

1) ***Trait Empathy*:** Participants' trait empathy was measured using the IRI [48], a 28-item survey answered on a 5-point Likert scale ranging from "does not describe me well" to "describes me very well." This instrument assesses an individual's cognitive and affective components of their empathy [47]; those two components have been deemed as necessary to understand the users' needs in engineering design [49]. The instrument was utilized in prior research in assessing the empathic tendencies of engineering students [53, 138, 139]. The IRI includes 4 subscales (perspective taking, fantasy, empathic concern, and personal distress), each made up of 7 different items. For example, an item in empathic concern is "I often have tender, concerned feelings for people less fortunate than me."

For internal reliability purposes, we calculated Cronbach alpha values for each subscale across each of the times we collected the data. A high Cronbach's α [140] was observed for fantasy (problem formulation $\alpha = 0.82$, concept generation, $\alpha = 0.83$, concept selection $\alpha = 0.91$, final design $\alpha = 0.90$), perspective-taking (problem formulation $\alpha = 0.76$, concept generation, $\alpha = 0.78$, concept selection $\alpha = 0.82$, final design $\alpha = 0.80$), empathic concern (problem formulation $\alpha = 0.77$, concept generation, $\alpha = 0.80$, concept selection $\alpha = 0.80$, final design $\alpha = 0.86$), and personal distress (problem formulation $\alpha = 0.78$, concept generation, $\alpha = 0.83$, concept selection $\alpha = 0.85$, final design $\alpha = 0.87$)

2) ***Empathic Self-Efficacy*****:** The empathic self-efficacy of participants was measured through a two-question survey derived from work by Raviselvam et al. [13, 20], that asked respondents to rate their ability to understand and solve design issues for the end-user. Specifically, the questions were (1) "I feel that I understand the behavior and mindset of the end-user," and (2) "I feel that I will be able to help solve their issues."

3) ***Personality Traits*****:** Personality traits were measured using the short Five Factor Model (FFM) online questionnaire [141], a short form of the IPIP-NEO (International Personality Item Pool Representation of the NEO PI-R. Specifically, the results of the 120-item survey assigns participants a score (ranging from 0 to 100) on each of the five personality traits: Extraversion, Agreeableness, Conscientiousness, Neuroticism, and Openness. The 120-item survey asked respondents to rate their agreement on 120 different items; for example, "worry about things", "make friends easily," and "make people feel welcome."

4) ***Risk-Taking Attitudes*****:** Risk taking attitudes were measured using a 30-item shortened version of the psychometric domain-specific risk-taking (DOSPERT) scale [142] due to the subscales' relevance in design-related tasks and its prior utilization in engineering design education research [143]. The instrument includes the following subscales: health/safety, ethical, social, recreational, and financial risk-taking attitudes. Specifically, participants were asked to rate their likelihood of engaging in the described activity or behavior. For example, items include "disagreeing with an authority figure on a major issue," "driving a car without wearing a seat belt." and "speaking your mind about an unpopular issue in a meeting at work."

Table 3.2 Summary of the data collection instruments

Name	Description	Reference
Trait Empathy (Interpersonal Reactivity Index)	A 28-item survey that includes 4 subscales: *perspective taking*, *fantasy*, *empathic concern*, and *personal distress*	Davis [94]
Empathic Self-Efficacy	A two-question survey that measures the ability to understand and solve design issues for the end-user	Raviselvam et al. [19, 20]
Personality (Short Five Factor Model)	A 120-item survey that assigns a score on each the five personality traits: Extraversion, Agreeableness, Conscientiousness, Neuroticism, and Openness	Johnson [137]
Risk-Taking (Domain-specific risk-taking (DOSPERT))	A 30-item survey that evaluates one's risk-taking attitudes on four subscales: health/safety, ethical, social, recreational, and financial risk-taking attitudes	Weber et al. [138]

CHAPTER **4**

ARE YOU FEELING ME? AN EXPLORATION OF EMPATHY DEVELOPMENT IN ENGINEERING DESIGN EDUCATION

This chapter is based on work submitted for publication to the Journal of Mechanical Design in January 2020. This work is multiple-authored by Mohammad Alsager Alzayed, Dr. Christopher McComb, Dr. Jessica Menold, Jacquelyn Huff, and Dr. Scarlett Miller. Mohammad Alsager Alzayed is the lead author on the paper, and Dr. Scarlett Miller and Dr. Christopher McComb helped advise this work.

4.1 Abstract

The first manuscript of the dissertation investigated the development of students' empathy in the design process and the factors that impact that development. This investigation is important since having empathy in the design process can help engineers relate to the end-user by identifying what and why certain experiences are meaningful. While there have been recent efforts to identify the factors that impact empathic tendencies in engineering, there has been limited evidence on how a students' trait empathy or empathic self-efficacy develops over the course of a design project or what factors impact this development. As such, the goal of the first manuscript was to explore the development of students' trait empathy and empathic self-efficacy development and identify the underlying impact of the design project's context and the course instructor. The study was conducted with 103 engineering students involved in an 8-week design project that involved four design stages (problem formulation, concept generation, concept selection, and final conceptual

design). The results from this study highlighted that students' trait empathy and empathic self-efficacy did not increase across the design stages, and the context of the design problem did not impact students' empathy development. Meanwhile, students displayed lower empathic self-efficacy in one of the course sections, and interviews with the course instructors revealed that the lack of accessibility to the end-user might have constricted students from developing empathy. These insights call for future research that could empirically assess the impact of trait empathy and empathic self-efficacy in driving design outcomes in the later design stages, which could increase engineering educators' awareness of the role of empathy in the engineering classroom.

4.2 Introduction

Empathy, or one's ability to understand the feelings and circumstances of others [144], has been found to help engineering designers develop a deeper understanding of the design problem [75]. Empathy may be particularly important in the early conceptual stages of the design process [7] as it involves a designer's attempt to "relate to [the user] and understand the situations and why certain experiences are meaningful to these [users]" ([8], p.. 67). If empathy is not developed early in the design process, there may be a mismatch between the final design and the requirements of the end user [9], ultimately leading to costly redesign efforts [10].

From an educational perspective, recent research has identified a potential relationship between empathic design experiences (e.g., simulating visually impaired scenarios) and engineering students' ability to generate creative ideas [11-13]. Additionally, students' perceptions of the relevance of their coursework in impacting the world have been shown to increase with empathic experiences, such as involving students in the use of a wheelchair [14]. These examples align with the recent push to transform engineering education from having a sole focus on technical skill development to the creation of 'holistic engineering education' [15-17]. This approach emphasizes the development of engineers who are able to engage with a broad range of stakeholders [15], understand different cultural expectations [16], and develop affective disposition skills [17]. This is particularly important in engineering design education because designers often design for people who are unlike themselves and must understand the needs of those diverse users [18, 19] to subsequently solve their problems [11, 12]. While there have been some recent efforts to identify the factors that impact empathic tendencies in engineering design, such as having a personal connection to the population being studied [20] and participating in simulated empathic scenarios [13] during short-form workshops, there is limited evidence on how a student's empathy develops over the course of an engineering class project or what factors impact this development. Without this knowledge, we do not know when or how to intervene in engineering education to create empathic engineers.

In light of this, the main goal of the current chapter was to explore the development of students' trait empathy and empathic self-efficacy development in an 8-week design project, and the underlying impact of the design context and course instructor on that development. The design context and course instructor were selected as the drivers of interest since different design contexts (e.g., humanitarian engineering projects) can require students to understand the culture and context of an end-user who is often very different from themselves [65-67]. Similarly, the course instructor is important as prior work has identified that engineering educators may stress empathy development at different levels because they may empathy as "a plus but … not what is really necessary to be a good engineer" ([71], p. 149). The results of this research provide some of the first evidence on the transitive nature of empathy in engineering education and formalize the impact of the design context and course instructor on students' empathy development.

4.3 Research Questions

Based on this prior work, the main goal of the current study was to explore the development of students' trait empathy and empathic self-efficacy in an 8-week design project and the underlying impact of the design context and course instructor on student empathy. The present study involved investigating the trajectory of students' trait empathy and empathic self-efficacy across the following four stages of the design *process (problem formulation, concept generation, concept selection, and final conceptual design),* which occurred in weeks 1, 5, 6 and 8 of the study, respectively. The results from this study establish foundational knowledge that is essential for the design of interventions geared towards empathy development in engineering design education. Specifically, the study was developed to answer the following research questions (RQs):

RQ1: Do students' trait empathy and empathic self-efficacy develop across design stages? The first question was developed to understand whether student's trait empathy and empathic self-efficacy increased across the four design stages (problem formulation, concept generation, concept selection, and final conceptual design). It was hypothesized that participants' trait empathy and empathic self-efficacy would increase across all design stages as prior work on engineering graduate students found that trait empathy can be developed through in-class projects [53], and participating in design workshops increased empathic self-efficacy [13, 20].

RQ2: Is the development of students' trait empathy and empathic self-efficacy impacted by the design problem context and the course instructor? The second research question sought to assess whether factors such as the context of the design problem or course instructor impacted participants' trait empathy and empathy self-efficacy development in the 8-week design project. It was hypothesized that participants working on projects in developing world contexts would develop more trait empathy and empathic self-efficacy than those working on projects in a developed world context since developing world contexts may present a larger challenge for students to understand the culture and context of an end-user who is often very different from themselves [65-67]. Additionally, it was hypothesized that the course instructor impacted participants' trait empathy and empathic self-efficacy development since prior work found differences in instructors' beliefs on the role of empathy in engineering [71].

RQ3: What were students' perceptions of their own empathy development and the importance of empathy in the design project? While the first two research questions sought to *empirically* investigate students' trait empathy and empathic self-efficacy development, the third research question was developed to understand students' *perceptions* of their empathy development and the role of empathy in the 8-week design project. Based on prior work [53], it was hypothesized that participants would have positive perceptions of their empathy development and that participants working on developing world contexts would have increased perceptions of their empathy development [65, 66, 145]. It was also hypothesized that perspective-taking tendencies would be most prevalent in student discussions due to its relevance in engineering design as a means of helping them understand the needs of users that are different from themselves [146]. Finally, it was hypothesized that participants' perceptions would not match the empirical findings since students might be biased to say they were empathic, i.e., self-serving bias [39], with students making more attributions for positive events than negative events [41, 42] to take credit for their success (e.g., increase in empathy) [43].

4.4 Methodology

In order to answer these research questions, a study was conducted with 103 first-year engineering design students who were in four sections of an introduction to engineering design course taught by three instructors at the Pennsylvania State University. The course provides students with the opportunity to go through an in-depth 8-week design project. Chapter 3 provides a detailed explanation of the data collection procedure.

Of importance to the study presented in this chapter, participants were asked to complete the Trait Empathy and Empathic Self-Efficacy surveys completed in week 1 of the study at the end of week 4, the end of week 5, and the beginning of week 9. In the week following the completion of the design project, a member of the research team gave a lecture to all four course sections on the importance of empathy in engineering design. After the 75-minute interactive lecture, participants were asked to submit a 1-page single spaced reflection essay that was due Friday of that week. Participants were asked to reflect on their perceptions of their own empathy development (increased, decreased, did not change) and the perceived importance of empathy across the design stages, see section 3.2 for details on the reflection assignment.

Finally, to better understand the differences between the three educational contexts, the three course instructors were interviewed after the course ended. The main goal of the interview was to understand how the different in-class activities impacted participants' empathy development during the 8-week project. The interview protocol is attached in Appendix A.

4.4.1 Content Analysis

To analyze participants' responses on the reflection essays, a codebook was developed through an abductive analysis [147] approach, which takes into account prior literature on trait empathy, while also being responsive to the nature of the data. Specifically, the responses were coded using the four trait empathy subscales (perspective-taking, fantasy, personal distress, and empathic concern) as *priori* codes, see Table 4.1. Notably, the data was coded at the paragraph level and more than one empathic tendency was coded for the same paragraph in some cases.

Table 4.1 Description of the empathic tendencies used to code the reflection essays

Empathic Tendency	Description
Perspective-Taking	The respondent's tendency to adopt the perspectives of other people and see things from their point of view
Empathic Concern	The respondent's tendency to experience feelings of warmth, compassion, and concern for the observed individual
Personal Distress	The respondent's tendency to experience feelings of fear, apprehension, and discomfort at witnessing the negative experiences of others
Fantasy	The respondent's tendency to transpose themselves imaginatively into the feelings and actions of fictitious characters in books, movies, and plays
Not Explicitly Stated	It is not clear which empathic indicator the respondent is referring to

The data for each of the above subscales were initially open coded and then further clarified and re-grouped through axial-coding [148] into secondary themes using constant comparative methodologies through a post-positivist paradigm [149, 150]. This paradigm is helpful for analyzing the essays with an existing theory (trait empathy) using the respondents' experiences during the design project while highlighting that each student understands the world differently [151, 152]. To ensure inter-rater reliability, two raters (PhD Industrial Engineering student and an undergraduate Industrial Engineering student) coded a 45% overlap of the essays using NVivo Pro

[153] and an acceptable inter-rater reliability (Cohen's Kappa = 0.81) [154] was achieved. The final coding structure is synthesized and presented in Appendix B. Additionally, after analyzing the quantitative survey results, the qualitative data from the interviews with the course instructors were analyzed to better understand instructors' perceptions on (1) why empathy did not change, (2) why the design context did not impact empathy?

4.5 Data Analysis and Results

This section highlights the results with reference to our research questions. Statistical analyses were computed using SPSS 25.0; a significance level of 0.05 was used in all analyses. The results are presented as mean ± standard deviation (SD) unless otherwise noted.

4.5.1 RQ1: Does students' trait empathy and empathic self-efficacy develop across the four design stages?

The first research question was developed to understand if participants' trait empathy and empathic self-efficacy changed between the problem formulation, concept generation, concept selection, and final conceptual design stages, which occurred in weeks 1, 5, 6, and 8 of the study respectively. It was hypothesized that student's trait empathy and empathic self-efficacy increased across all design stages as prior work on engineering graduate students found that trait empathy can be developed through in-class projects [53], and participating in design workshops increased empathic self-efficacy [13, 20].

In order to assess whether participants' **trait empathy** changed across those design stages, four one-way repeated measures Analyses of Variances (ANOVAs) were computed with the independent variable being design stage (problem formulation, concept generation, concept selection, and final conceptual design) and the dependent variables being the four interpersonal reactivity indices (perspective-taking, fantasy, empathic concern, and personal distress). Prior to these analyses, assumptions were checked. Specifically, assessment of the box-and-whisker plot revealed one outlier from the perspective-taking scores and two outliers from the personal distress scores at the problem formulation stage, and one outlier from the personal distress scores at the concept selection stage. The outlier was found to have no significant impact on the significance of the results, and therefore, the full analysis is presented here. Normality was confirmed for each of the dependent variables by visually inspecting the histograms and Q-Q plots, and the assumption of sphericity was not met, $p < 0.05$ for all four repeated measures ANOVAs, Epsilon (ε) was used to correct the repeated measures ANOVA. Finally, Levine's Test for Equality of Variances revealed that the scores from the IRI subscales did not violate the assumption of homogeneity of variances ($p > 0.05$). Thus, the analysis proceeded.

The results of the ANOVAs showed that there was a statistically significant difference in the

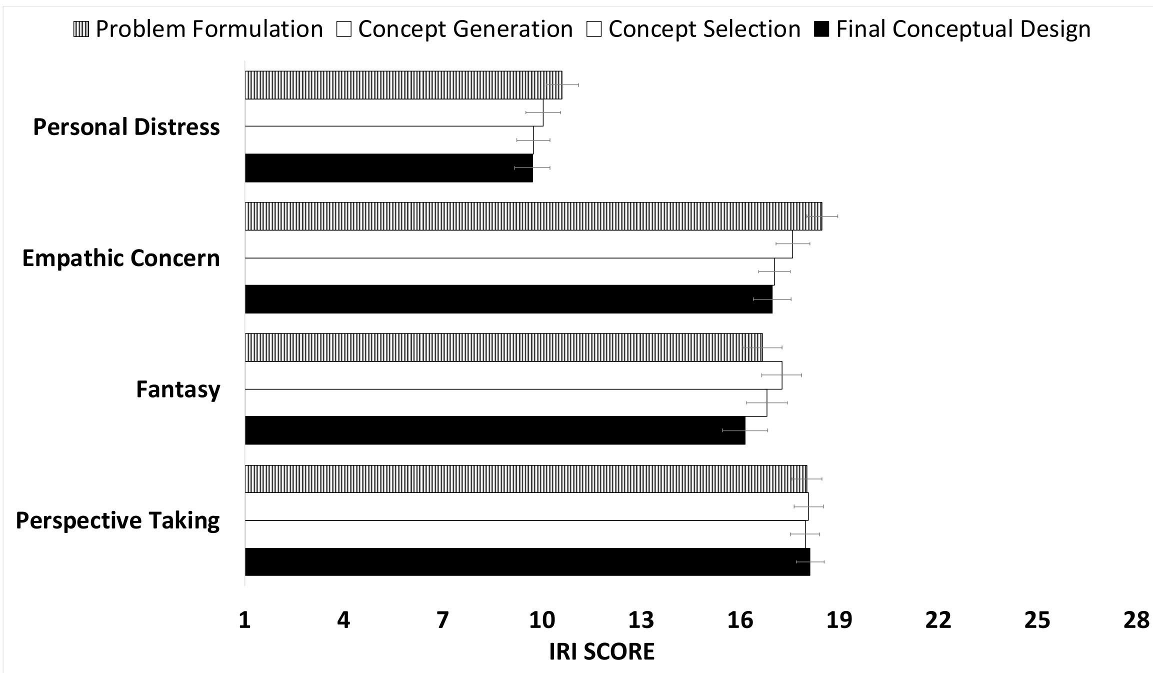

Figure 4.1 Average IRI scores of participants (error bars represent ±standard error). The maximum possible score for each IRI subscale was 28.

empathic concern, $F(2.606,252.741) = 8.515$, $p < 0.01$, $\eta_2 = 0.081$, and **personal distress** $F(2.583,250.532) = 3.330$, $p = 0.026$, $\eta_2 = 0.033$), across the design stages, However, there were no statistically significant differences for **perspective-taking** ($F(2.568,249.131) = 0.080$, $p = 0.971$, $\eta_2 < 0.01$), or **fantasy (**$F(2.361,229.013) = 2.718$**,** $p = 0.059$, $\eta_2 = 0.027$) with participants showing no change in their perspective-taking, and fantasy tendencies across the four stages, see

Figure 4.1.

To understand how empathic concern and personal distress changed, pairwise comparisons were run with reported 95% confidence intervals, and *p*-values are Bonferroni-adjusted. The post-hoc results showed that participants' **empathic concern** scores in the problem formulation stage was 1.42, 95% CI [0.475, 2.402], higher than the concept selection stage, and 1.510, 95% CI [0.454,2.567], higher than the final conceptual design stage, $p < 0.001$. Additionally, the post-hoc results showed that the participants' **personal distress** scores in the concept generation stage was 1.102, 95% CI [0.222, 1.982], higher than the concept selection stage, $p < 0.001$.

Next, in order to assess whether participants' **empathic self-efficacy** changed across those design stages, two one-way repeated measures Analyses of Variance (ANOVA) were computed with the independent variable being design stage (problem formulation, concept generation, concept selection and final conceptual design) and the dependent variables being scores from the two self-efficacy questions (ability to understand the end-user and ability to design). Prior to these analyses, assumptions were checked. Specifically, the assessment of the box-and-whisker plot revealed 11 outliers from the scores from the first self-efficacy item and 10 outliers from the second item. The outlier was found to have no significant impact on the significance of the results, and therefore, the full analysis is presented here. Normality was confirmed for each of the dependent variables by visually inspecting the histograms and Q-Q plots, and the assumption of sphericity was not met for the perceived ability to understand, $p < 0.05$, but not for the perceived ability to design, $p = 0.105$. Therefore, epsilon (ε) was used to correct the repeated measures ANOVA for the first self-efficacy item. Finally, Levine's Test for Equality of Variances revealed that the scores did not violate the assumption of homogeneity of variances ($p > 0.05$). Thus, the analysis proceeded.

The results of the ANOVAs showed that there was no statistically significant difference in participants' perceived **ability to understand**, $F(2.620,254.152) = 1.305$, $p = 0.274$, $\eta_2 = 0.013$, and perceived **ability to design** for the end-user, $F(3,291) = 1.298$, $p = 0.275$, $\eta_2 = 0.013$, indicating that participants' self-efficacy did not evolve across the design stages.

These results partially refute our hypothesis that participants' trait empathy and empathic self-efficacy increased. Specifically, the results indicated that participants' empathic concern and personal distress decreased across the design stages. These results indicated that the educational activities (e.g., empathy map, a user needs assessment, idea generation, etc.) were not effective in driving students' empathy development. However, while this study *empirically* assessed students' trait empathy and empathic self-efficacy, it did not involve empathy-evoking interventions in all stages of the design process. Given the need for engineer designers to understand the needs of diverse users [18, 19], these findings call engineering educators to deliberately instill empathy-specific interventions throughout all stages of the design process, and future research is needed to identify which activities are successful in terms of empathy development.

4.5.2 RQ2: Is the development of students' trait empathy and empathic self-efficacy impacted by the design context and course instructor?

The second research question sought to assess whether factors such as the context of the design problem or course instructor impacted participants' trait empathy and empathy self-efficacy development in the 8-week design project. Based on prior work [65, 66, 145], it was hypothesized that participants working on projects in developing world contexts developed more trait empathy and empathic self-efficacy than those working on projects in a developed world. Additionally, it was hypothesized that the course instructor impacted student's trait empathy and empathic self-efficacy development since prior work found differences in instructors' beliefs on the role of empathy in engineering [71].

In order to assess the impact of the context of the design problem on participants' **trait empathy** and **empathic self-efficacy**, six 2-way Analysis of Covariances (ANCOVAs) were conducted with (1) perspective-taking, (2) fantasy, (3) empathic concern, (4) personal distress, (5) ability to understand and (6) ability to design scores from final conceptual design as the dependent variables and with design problem context as the between-subjects factors and with (1) perspective-taking, (2) fantasy, (3) empathic concern, (4) personal distress, (5) ability to understand and (6) ability to design scores from problem formulation as the covariate for each of the ANCOVAs respectively. An ANCOVA was selected since participants had different starting points of trait empathy and empathic self-efficacy. Before analysis, all assumptions were checked. Since several outliers existed in the data, the analysis was run both with and without the outliers.

No differences were found in the outcomes of the analysis; thus, the full results are reported here. Normality was confirmed for each of the dependent variables by visually inspecting the histograms and Q-Q plots. There was homogeneity of regression slopes, a linear relationship between IRI scores at both design stages, and homoscedasticity within each combination of groups of the independent variables. Finally, Levine's Test for Equality of Variances revealed that the assumption of homogeneity of variances was met. Thus, the analysis proceeded.

The results revealed that there was not a significant main effect of design problem context, $p > 0.05$ for the scores of (1) perspective-taking, (2) fantasy, (3) empathic concern, (4) personal distress, (5) ability to understand and (6) ability to design, see Table 4.2. These results refute our hypothesis that the context of the design problem would influence participants' trait empathy or empathic self-efficacy development, indicating that participants solving problems in the developing world did not develop more empathy than participants with projects contextualized in the developed world.

Table 4.2 Summary of ANCOVA results

Measure	Factor	F (2,97)	*P*	η2
Perspective-Taking	Context	2.795	0.098	0.028
	Covariate	61.384	< 0.01	0.388
Fantasy	Context	0.017	0.898	0.526
	Covariate	107.776	< 0.01	<0.01
Empathic Concern	Context	0.033	0.503	<0.01
	Covariate	104.155	<0.01	0.518
Personal Distress	Context	0.389	0.534	<0.01
	Covariate	119.799	<0.01	0.553
Ability to Understand	Context	1.842	0.178	0.019
	Covariate	2.961	0.088	0.030
Ability to Design	Context	0.276	0.600	0.003
	Covariate	0.370	0.545	0.004

Next, in order to determine the impact of the course instructor (Instructor A or Instructor B) on participants' trait empathy and empathic self-efficacy, six two-way ANCOVAs were computed with (1) perspective-taking, (2) fantasy, (3) empathic concern, (4) personal distress, (5) ability to understand and (6) ability to design scores from final conceptual design as the dependent variables and with course instructor as the between-subjects factors and with (1) perspective-taking, (2) fantasy, (3) empathic concern, (4) personal distress, (5) ability to understand and (6) ability to design scores from problem formulation as the covariate respectively.

The results revealed that there was not a significant main effect of the course instructor, $p > 0.05$ for (1) perspective-taking, (2) fantasy, (3) empathic concern, (4) personal distress. However, the course instructor was significant, for both self-efficacy items, **ability to understand end-user**, $F (1,48) = 7.041$, $p = 0.011$, $\eta_2 = 0.128$, and **ability to design for end-user**, $F (1,48) = 5.513$, $p = 0.023$, $\eta_2 = 0.103$. To understand the differences between the two instructors, pairwise comparisons were run were reported 95% confidence intervals, and *p*-values are Bonferroni-adjusted. The post-hoc results showed that participants' ability to understand the end-user was 0.756, 95% CI [0.221, 1.291], higher for participants in Instructor B's class when compared to Instructor A's class, $p = 0.007$. Additionally, the ability of participants in instructor B's class to design for the end-user was 0.65, 95% CI [0.093, 1.207] higher than participants in Instructor A's course, $p = 0.023$, indicating that the course instructor impacted participants' empathic self-efficacy development.

The results from this research question partially refute our hypothesis that participants designing for developing world contexts would have higher development in their trait empathy and empathic self-efficacy. A possible explanation might be that participants were challenged when coming up with ideas for the end-user that they could not directly relate to [145], or that students over-estimating their abilities in the first week of the project and subsequently realized how much they didn't know about the end-user [155]. In order to deepen the understanding of these quantitative results, the qualitative data from the interviews with the course instructors were analyzed to better understand instructors' perceptions on (1) why empathy did not change, (2) why the design context did not impact empathy? Instructors A and B, whose projects are contextualized in the developing world, stressed the lack of accessibility to the user as being a potential reason for not encouraging empathy development. For instance, Instructor B mentioned the term disassociated empathy,

> *"I felt like particularly in this class there was a level of disassociated empathy…. what I mean is that because the students in this course were never able to talk to a user one on one in real life and were reliant on news stories, videos, studies. I think, in a sense, they developed empathy for the problem, so they developed empathy for the situation that these users were in, but I don't think that they developed empathy for the user themselves."*

Instructor A had a similar observation; they stated, "I think that one thing that might have restricted them from developing empathy is not having ready access to their users."

Additionally, instructors discussed potential reasons why empathy may not have developed during the later design stages. For example, Instructor A noted how empathy was counter-productive in idea generation for a particular team, "I'm gonna say it was her empathy that was blocking her from thinking of ideas like every time she would think of an idea she would say, 'yeah but this really wouldn't work for them. This wouldn't solve it,' and sometimes you just need to keep that aside to generate ideas, so it kind of limited their ability to design." In addition, Instructor B discussed the role of empathy in the concept selection stage; they mentioned, "I think it's just a different phase of the design process that doesn't necessarily call on empathy as directly as a salient skill, so I think that probably during concept selection [empathy] wasn't as helpful because at that point we use very quantitative tools." Instructor A also mentioned, "It's beneficial to offer some different approaches for performing engineering design right and some that can be qualitative and empathic, and some of it can be more quantitative and less empathic." Additionally, Instructor C mentioned, **"**I think in the stages where it was like a little slower, a little more deliberate, there was good empathy development, and the stages that were a little rushed and brought in more of the hands-on prototyping, students didn't develop a whole lot of empathy beyond what they already had in my opinion."

The interviews with course instructors highlighted several constraints in the applications of empathy building-activities which could have an impact on students' empathy development. For instance, instructors discussed that the lack of accessibility to the end-user could have constricted students from developing empathy for the end-user. Additionally, instructors discussed that the later design stages (concept generation and selection) involved less deliberate empathy-invoking activities compared to the earlier design stages. Furthermore, one of the three interviewed instructors discussed that the time spent on each activity might have an impact on students' empathy development. These insights call for future research that could assess the impact of pedagogical activities that involve an interaction with the end-user on students' trait empathy development; these activities include simulating user scenarios [13, 20] and conducting interviews with the end-users [156].

4.5.3 RQ3: What were students' perceptions of their own empathy development, and do their perceptions align with the empirical results?

While the second research question sought to *empirically* investigate students' trait empathy and empathic self-efficacy development, the third research question was developed to understand participants' *perceptions* of their own empathy development in the 8-week design project. Based on prior work [53], it was hypothesized that participants positively perceived their empathy development and that those perspective-taking tendencies were the most prevalent in student discussions due to its relevance in engineering design.

In order to answer this research question, the reflection essays were coded using an abductive content analysis approach [147], which takes into account prior literature on trait empathy, while also being responsive to the nature of the data; see Appendix B for the final codebook. Specifically, we marked the discussion of the four IRI scales (perspective-taking, fantasy, personal distress, and empathic concern) or "not explicitly stated," which indicated that it was not clear which empathic indicator the respondent was referring to. The results from the content analysis found that participants rarely discussed their **personal distress** (n = 2) or **fantasy** (n = 1) tendencies in the reflection essays. Instead, most participants were referring to their **perspective-taking** (n = 67) and **empathic concern** (n = 39) tendencies. Specifically, participants working on developing world problems discussed **empathic concern** tendencies more than participants working on developed world projects, see Figure 4.2.

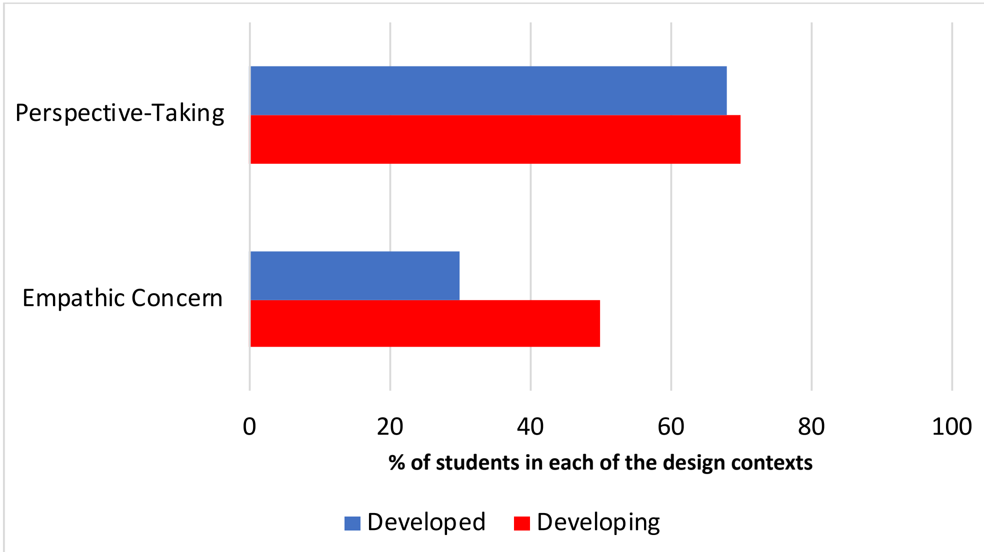

Figure 4.2 Discussion of empathic tendencies between design contexts

While the quantitative results from RQ2 found that the design context did not impact students' trait empathy or empathic self-efficacy development, these results indicated that **empathic concern** was discussed by more participants working on developing world problems when compared to participants working on developed world problems, indicating that participants were aware of their feelings of compassion and warmth for those less fortunate than them [48]. However, it is not known if the translation of those feelings necessarily leads to positive design outcomes. Future work should empirically address this aspect of empathy development.

Emerging themes were linked to the **perspective-taking** and **empathic concern** tendencies as well as the discussion of *general* empathy, where it was not explicitly stated which empathic tendency the student was referring to. Specifically, the following themes emerged from **perspective-taking**: concept generation, concept selection, other, motivation, teamwork, user needs assessment, and culture understanding (see table 4.3). Similarly, the following themes emerged from **empathic concern**: concept generation, concept selection, other, motivation, and user needs assessment (see table 4.3). These findings indicated that participants were referring to their perspective-taking and empathic concern tendencies, particularly at the user needs assessment and concept generation stages of the design process. These results indicated that particular empathic tendencies might be relevant to different stages of the design process, which future research should address.

Table 4.3 Percentage of students discussing each theme that relates to each empathic tendency

Empathic Tendency	Concept Generation	Concept Selection	Prototyping & Detailed Design	Teamwork	Motivation	User Needs Assessment	Culture Understanding	Other
Perspective Taking	24	7	-	9	4	35	10	11
Empathic Concern	28	4	-	-	20	22	-	26
General Empathy	28	29	16	4	6	7	10	-

Finally, the following themes emerged with participants' discussion of their *general* empathy: concept generation, concept selection, prototyping & detailed design, motivation, teamwork, user needs assessment, and cultural understanding, see Table 4.3. While **perspective-taking** and **empathic concern** tendencies were only prevalent in the discussion of the earlier design stages (user needs and concept generation), participants' *general* empathic tendencies were discussed with reference to all the design stages, particularly the later stages such as concept selection and prototyping. These results indicated that particular empathic tendencies might be relevant to different stages of the design process. These findings warrant future work that would empirically assess the impact of particular empathic tendencies (perspective-taking, fantasy, empathic concern, personal distress) in driving students' design outcomes (e.g., creativity, motivation, etc.) across each of the design stages.

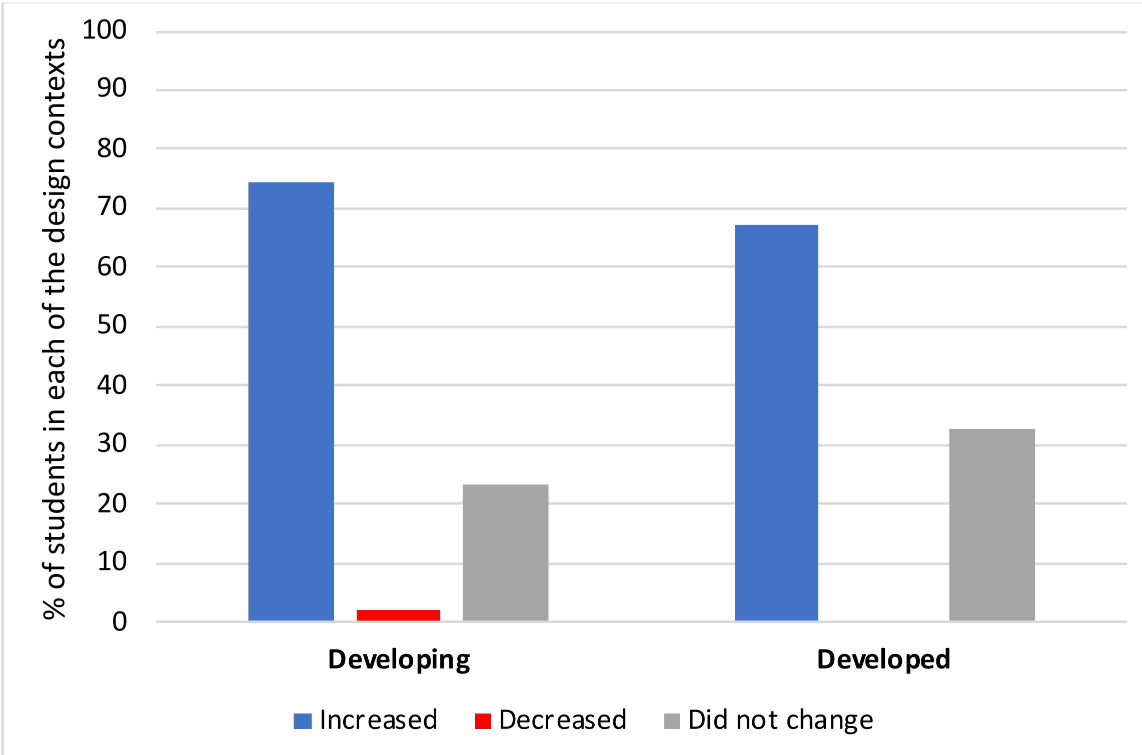

Figure 4.3 Students' perceptions of their empathy development categorized by design context (developing world versus developed world)

In addition to the emergence of the above themes, we also analyzed participants' perceptions of their empathy development, since participants were explicitly asked to reflect upon that in the reflection essay. We coded their responses as follows: (1) the participant perceived their empathy to have increased, (2) the participant perceived their empathy to have decreased, (3) the participant perceived their empathy to have not changed, and (4) the participant did not mention their empathy development. The results indicated that the vast majority of participants (n = 66) perceived their empathy to have developed over the course of the 8-week project. For instance, participant 12 mentioned, "however, after few weeks I noticed that the empathy of our group has unbelievably developed because in our research we saw how people in Dhaka are suffering and struggling to live with unsafe drinking water." Meanwhile, 26 respondents felt that their empathy did not change; for example, participant 48 stated, "looking from within, I would say that my empathy probably hasn't changed much from the start of the project, or at least this specific project didn't make my empathy any better or worse." Four respondents did not directly address the question, and thus, their responses were coded as "did not mention their empathy development." The results revealed that were no differences in perceived empathy development between participants in the developing world sections versus those in the developed world sections, see Figure 4.3.

Finally, to assess whether participants' perceptions align with the empirical results, statistical analyses were performed to understand the relationship between participants' perceptions of their empathy development and their actual change in empathy. Specifically, six different Mann-Whitney U tests [157] were run to determine if there were differences between participants' perceptions of their empathy development (increased, did not increase) and participants' actual change in perspective-taking, fantasy, empathic concern, and personal distress, ability to understand end-user and ability to design for end-user. The participants' actual change in **perspective-taking, fantasy, empathic concern,** and **personal distress**, **ability to understand end-user** and **ability to design for end-user** were not statistically significantly different between those that believed their empathy increased compared to those that did not believe their empathy increased, $p > 0.05$, indicating that participant' perceptions of their empathy development did not match the empirical findings.

Next, statistical analyses were performed to understand the relationship between participants' *discussion* of the empathic tendencies and whether or not they developed those empathic tendencies. Since **fantasy** and **personal distress** tendencies were scarcely discussed in the reflection essays, we only analyzed the discussion of **perspective-taking** and **empathic concern**. Specifically, a Mann-Whitney U test was run to determine if there were differences between participants' discussion of perspective-taking and participants' change in perspective-taking over the 8-week project. The change in **perspective-taking** was not statistically significantly different between those that mentioned **perspective-taking** (Mdn = 0.00) compared to those that did not mention **perspective-taking** (Mdn = -1.00) in the reflection essays, U = 1056.5, z = 1.868, p = 0.062. Additionally, the change in **empathic concern** tendencies was not statistically significantly different between those that mentioned **empathic concern** (Mdn $= -1.00$) compared to those that did not mention **empathic concern** (Mdn $= -2.00$) in the reflection essays, U = 1203.5, z = 1.531, p = 0.136.

The results from this research question partially support our hypothesis that participants would have positive perceptions of their empathy development, with the vast majority of participants perceiving their empathy to have developed over the course of the 8-week project. Both **perspective-taking** tendencies and **empathic concern** tendencies were prevalent in participants' discussion, with participants in the developing world contexts discussing **empathic concern** more than those in the developed world sections. These results are promising, as they indicate that participants were reflecting on both the cognitive (**perspective-taking**) and affective (**empathic concern**) components of their empathy [158]. This is important as Hoffman [159], Shantz [160], and Strayer [158] agreed that both cognitive and affective components shape the empathic nature of individuals. However, participants' perceptions of their empathy development did not align with the empirical findings. Specifically, the results indicated that participants' discussion of **perspective-taking** and **empathic concern** in their reflection essays did not necessarily mean they developed those tendencies.

This may be due, in part, to participants' attributional bias, with participants' motivation to maintain positive self-views [41, 42]. For example, students might be tempted to make more attributions for their empathy development rather than report a drop in empathy to maintain their positive self-image [41-43]. Additionally, social desirability biases, an individual's attempt to create a favorable image of themselves [40], might also impact participants' misaligned perceptions of their empathy development. These biases are relevant in course evaluations [39], similar to the reflection assignment, where participants might take credit for their success (e.g., increase in empathy) to protect their self-esteem [43]. These results indicate that engineering education researchers should not rely solely on students' perceived empathy when devising or assessing pedagogical interventions aimed at empathy development.

4.6 Discussion

The main goal of the current study was to explore the development of students' trait empathy and empathic self-efficacy development in an 8-week design project, and the underlying impact of the design context and course instructor on that development. The main findings from the study are as follows:

- Students' trait empathy and empathic self-efficacy did not increase across the design stages, and the context of the design problem did not impact students' empathy development.
- Interviews with the course instructors revealed that the lack of accessibility to the end-user might have constricted students from developing empathy.
- Students' perceptions of their empathy development did not align with the empirical results, and students reflected on their perspective-taking and empathic concern tendencies but did not mention their fantasy and personal distress tendencies.

The first finding from the study indicated that students did not develop their trait empathy and empathic self-efficacy and that the design problem had no impact on students' trait empathy and empathic self-efficacy. Specifically, the results indicated that participants' empathic concern and personal distress decreased across the design stages. The decrease in personal distress tendencies could be an indication of students' increased emotion regulation skills [50] since researchers have found that personal distress tendencies to be related to empathic over-arousal [50], emotional vulnerability [51], anxiety [51], and negative affect [52]. Additionally, students' decrease in empathy might be due, in part, to natural variations in their empathy and not necessarily be caused by the activities in the different design stages [161, 162]. However, these results call for future research that would assess the impact of personal distress and the three other IRI subscales on design outcomes.

The second finding of the study highlighted several constraints in the applications of empathy building-activities which could have an impact on students' empathy development. For instance, instructors discussed that the lack of accessibility to the end-user could have constricted the students from developing empathy for the end-user. This would be particularly the case for students working on developing world projects where students might be additionally challenged to understand the culture and context of an end user who is often very different from themselves [65-67]. Additionally, instructors discussed that the later design stages (concept generation and selection) involved less deliberate empathy-invoking activities compared to the earlier design stages. While this study involved user-centric activities across an 8-week design project, it did not particularly involve any form of interaction with the end-user. Thus, future work should examine and compare the impact of different pedagogical interventions that involve an interaction with the end-user; these interventions include but are not limited to the following: simulating user scenarios [13, 20] and conducting interviews with the end-users [156].

Finally, while the overall results from this study indicated that students are not developing empathy and that the design context was not helpful in impacting one's empathy, insights from students' reflection essays found positive perceptions of students' empathy development and their awareness of the importance of empathy in engineering design. Both perspective-taking tendencies and empathic concern tendencies were prevalent in students' discussion, with students in the developing world contexts discussing empathic concern more than those in the developed world sections, indicating that students were aware of their feelings of compassion and warmth for those less fortunate than them [48]. However, the translation of those feelings could, or could not, lead to positive design outcomes, which the future world should particularly address. Overall, these qualitative findings indicate that even though students did not necessarily develop their empathy, they are aware of the importance of empathy in engineering design and are tapping into both the cognitive (perspective-taking) and affective (empathic concern) components of their empathy [158]. This is important as Hoffman [159], Shantz [160], and Strayer [158] agreed that both cognitive and affective components shape the empathic nature of individuals. However, these results displayed contradictory with students' perceptions of their empathy development not aligning with the empirical findings. This may be due, in part, to students' attributional bias, with students attributing for positive events than for negative events [41]. This form of positive regard has been universally studied the general population where people are motivated to maintain positive self-views [42]. Additionally, social desirability biases, an individual's attempt to create a favorable image of themselves [40], might also impact students' misaligned perceptions of their empathy development. Indeed, these biases are relevant in course evaluations [39], similar to the reflection assignment, where students might take credit for their success (e.g., increase in empathy) to protect their self-esteem [43]. While the results from the interpersonal reactivity index are also self-reported and might incur social desirability biases, the instrument measures a multidimensional nature of empathy by assessing both the cognitive and affective components of empathy [47]. Thus, the prevalence of social desirability or attributional biases might be minimal compared to students' responses in the reflection essays. Taken as a whole, these results emphasize the need to not rely *solely* on students' perceptions of their empathy development, but rather to rely on empirical evaluations when assessing pedagogical interventions targeted at empathy development in engineering design education, which future work should particularly address.

4.7 Conclusions and future work

The main goal of the current study was to explore the development of students' trait empathy and empathic self-efficacy development in an 8-week design project, and the underlying impact of the design context and course instructor on that development. In order to achieve this goal, a study was conducted with 103 engineering students involved in an 8-week design project. The results from this study highlighted that students' trait empathy and empathic self-efficacy did not increase across the design stages, and the context of the design problem did not impact students' empathy development. Qualitative insights highlighted that the lack of accessibility to the end-user might have constricted students from developing empathy. Finally, students' perceptions of their empathy development did not align with the empirical results, and students reflected on their perspective-taking and empathic concern tendencies but did not mention their fantasy and personal distress tendencies.

There are several limitations that can lead to exciting avenues for future research. While the results presented in this paper depict the lack of students' change in trait empathy across a design project, future work is needed to extend the results over longer periods of time. While this study *empirically* assessed students' trait empathy and empathic self-efficacy development, it did not involve empathy-evoking interventions, which future research should assess to identify the more successful in-class activities, in terms of empathy development. Specifically, future work should examine and compare the impact of different pedagogical interventions on trait empathy development; these interventions include but are not limited to the following: simulating user scenarios [13, 20], delivering lectures on the importance of empathy, direct interactions (e.g., interviews) with users. Additionally, while self-efficacy is a critical educational outcome, future research should assess the customer needs to be generated by students as well as ideas the students have generated during the ideation activity to get a holistic assessment of students' creative abilities in the project, and its relation to their trait empathy and empathic self-efficacy. Finally, since there is no validated instrument to assess the cognitive and affective [47] components of empathy specifically in a design context, this study utilized Davis' IRI to assess empathy – an instrument that is originally contextualized in psychology rather than engineering design. Thus, due to the need to devise and assess pedagogical interventions geared at empathy development, this study calls researchers in engineering design to devise and validated a psychometric instrument that could assess the cognitive and affective components of empathy in a design context.

CHAPTER 5

EMPATHY VERSUS CREATIVITY? CAN TRAIT EMPATHY PREDICT CREATIVE CONCEPT GENERATION AND SELECTION?

The paper presented in this chapter is based on a conference paper accepted for publication in the proceedings of the Ninth International Design Computing and Cognition (DCC) conference [163]. The extension of this conference paper presented in this chapter will be submitted to the DCC Special Issue of the Artificial Intelligence for Engineering Design, Analysis, and Manufacturing Journal in June 2020. This work is multiple-authored by Mohammad Alsager Alzayed, Dr. Christopher McComb, Dr. Jessica Menold, Jacquelyn Huff, and Dr. Scarlett Miller. Mohammad Alsager Alzayed is the lead author on the paper, and Dr. Scarlett Miller and Dr. Christopher McComb helped advise this work.

5.1 Abstract

While Chapter 4 of this dissertation focused on examining students' empathy development and the factors that lead or dissuade students from being empathic, Chapter 5 turns the focus to formalizing the role of empathy in the concept generation and selection stages of the design process. This is important because the literature identifying the role of empathy in design is in conflict with a group of researchers advocating for the role of empathy in design, and are invested in devising empathy-invoking interventions, while other researchers warn designers from overly engaging in empathic design activities as these activities might send designers into the "empathy trap," also known as empathic vampirism, where the designer would end up designing for themselves if they over empathize. In addition, while the prior work investigating the role of

empathy in concept generation is in conflict, the role of empathy during concept selection has been scarcely researched. Without this knowledge, it is unclear *if*, *when*, or *how* empathy promotes design outcomes in an engineering design project.

Therefore, the current study was developed to identify the role of trait empathy in creative concept generation and selection in an engineering design student project. In order to achieve this, a study was conducted with 103 first-year engineering students during two design stages of an 8-week design project (concept generation and concept selection). The main findings from this research highlighted that empathic concern tendencies positively impacted the generation of more ideas, while personal distress tendencies negatively impacted the generation of more ideas. During concept selection, perspective-taking tendencies positively impacted participants' propensity for selecting elegant ideas. This research suggests that while empathy may be useful throughout the design, the utility of specific types of empathy vary depending upon the design stage. Overall, the study presented in this dissertation took the first step in encouraging empirical investigations aimed at understanding the role of trait empathy across different stages of the design process.

5.2 Introduction

The ability to understand and feel the needs and circumstances of others, also known as empathy, has been found to help designers develop a deeper understanding of the design problems they solve [75]. Empathy could be particularly important in the early conceptual stages (i.e., concept generation and selection [6]) of the design process [7] as it involves a designer's attempt to "relate to [the user] and understand the situations and why certain experiences are meaningful to these [users]" ([8], p. 67). As such, the design community has been invested in devising and assessing empathic design activities, such as simulating empathy-evoking scenarios [13, 20], in the design process [20, 53, 56, 71, 73, 74]. While empathy has been established as an essential component of design [7, 13, 20, 75], the role of empathy on impacting creative design outcomes is still unclear, especially during concept generation and selection. Formalizing the role of empathy in these earlier conceptual stages can save costs and effort [9], as the success of a product can be linked to the early conceptual stages of the idea's emergence [10], and being empathic in those stages can be a gateway to creative solutions to the design problem [7]. Studying the relationship between empathy and creativity is critical since creativity and innovation have been emphasized as necessary facets of design thinking in engineering education [57, 76-79].

At its current state, the literature identifying the role of empathy in design is in conflict. A group of researchers (e.g., Hess and Fila [49, 139]; Genco et al. [12]; Johnson et al. [11]; Raviselvam et al. [13, 20]) advocate for the role of empathy in design and are invested in devising empathy-invoking interventions, particularly at the concept generation. In contrast, other researchers, such as Mattelmäki, Vaajakallio, and Koskinen [81] caution designers from engaging in empathic design activities, as these empathy-invoking activities might end up in the "empathy trap"; their attempt to be empathic might trigger popular *directed* reflections from the users instead of providing radical innovations to the existing problems [81]. Similarly, Breithaupt [22] refers to this form of empathy as empathic vampirism, suggesting that the designer would end up designing for themselves if they over empathize [21].

While the prior work investigating the role of empathy in concept generation is in conflict, the role of empathy during concept selection has been *scarcely* researched. This is problematic since the concept selection stage is when designers narrow down the ideas generated during concept generation [6] and has been identified as one of the most critical stages that determine successful design [24, 26]. Studying designers' creativity during concept generation *solely* is not representative of the designers' creativity since the "availability of creative ideas is a necessary but insufficient condition for innovation" (p. 48, [25]).

Taken as a whole, prior work investigating the relationship between empathy and creative design outcomes during concept generation provides conflicting interpretations. Additionally, the role of empathy in concept selection has been scarcely researched. Thus, formalizing the role of an individual's trait empathy in driving design outcomes in the concept generation and selection stages of the design process could bring great clarity to the existing research. Thus, the main goal of this paper was to identify the role of trait empathy in creative concept generation and selection in an engineering design student project. The results from this research provide some of the first evidence that establishes the relationship between trait empathy and creativity in the concept generation and selection stages of the design process.

5.3 Research Objectives

Based on this prior work, the main objective of this study was to determine if or how engineering student trait empathy impacts their ability to generate and select creative concepts in an engineering design project. Figure 5.1 provides a summary of the factors investigated in this chapter. Specifically, the following research questions (RQs) were devised:

1. ***Can trait empathy be used to predict the number of ideas generated in an engineering design project?*** It was hypothesized that participants with higher trait empathy would generate more ideas due to prior work with engineering graduate students that found that trait empathy was related to their innovative self-efficacy [53].
2. ***Can trait empathy be used to predict the creativity of the ideas generated in an engineering design project?*** It was hypothesized that participants with higher trait empathy would generate more creative concepts due to prior work with engineering graduate students that found that trait empathy was related to their innovative self-efficacy [53].
3. ***Can trait empathy be used to predict the propensity for selecting creative ideas in an engineering design project?*** It was hypothesized that trait empathy would predict creative concept selection due to prior work with engineering graduate students that found that trait empathy was related to their innovative self-efficacy [53].

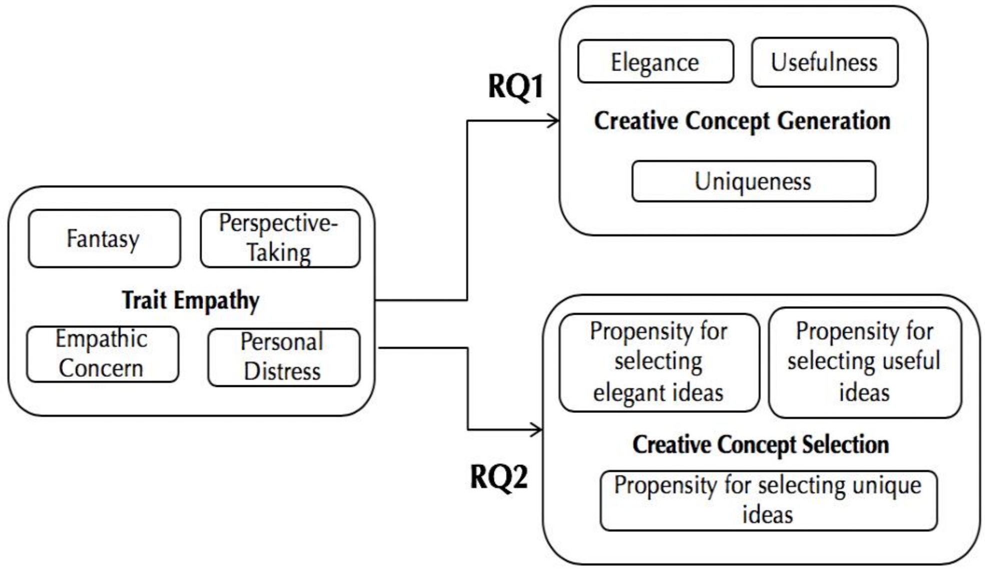

Figure 5.1 Summary of the factors investigated in Chapter 5

5.4 Methodology

In order to answer these research questions, a study was conducted with 103 first-year engineering design students who were in four sections of an introduction to engineering design course taught by three instructors at a large Northeastern university. The course provides students with the opportunity to go through an in-depth 8-week design project. Chapter 3 provides a detailed explanation of the data collection procedure.

Of importance to the study presented in this chapter, participants were involved in concept generation and concept selection activities. Specifically, during the concept generation stage (week 4), participants were involved in two brainstorming sessions: reverse brainstorming [130], where they were given 15 minutes to brainstorm bad ideas that would make the problem worse, and then individual brainstorming where they were asked to generate concepts for 20 minutes. During the concept selection stage (week 5), participants were asked to select concepts using a concept screening matrix. Participants were asked to complete the Trait Empathy survey at the end of week

4, immediately after the concept generation activity, and at the end of week 5, immediately after the concept selection activity. Chapter 3 provides a detailed explanation of the data collection instruments.

5.4.1 Design Creativity

In order to explore participants' creative design outcomes during the concept generation and selection stages, the following metrics were used. The remainder of this section explains the methodological approach taken to assess design creativity.

Number of Ideas: The number of ideas was calculated for each participant by counting the number of idea sheets completed by each participant during the individual ideation session. This aligns with the quantity metric from the work of Shah, Vargas-Hernandez, and Smith [164].

Consensual Assessment Technique (CAT)**:** The Consensual Assessment Technique [165] was used to assess the effectiveness of the ideas generated by the 103 participants. This technique has been widely used in prior research in engineering design [166, 167], and has been identified as a global measure of creativity [168, 169]. The CAT defines that an idea is creative when judges *independently* agree that it as creative [170]. Using a 6-point Likert Scale, the ideas were rated on the following criteria: overall creativity, usefulness, uniqueness, and elegance [171]. Specifically, (1) overall creativity relates to experts' judgement of the overall creativity of an idea, (2) uniqueness relates to overall perceptions of how original and surprising the idea was [171], (3) usefulness relates to the overall perceptions of value, logic, and how understandable the ideas were, while (4) elegance refers to the idea's "simplicity, insight shown, and conciseness of [the idea's] presentation" ([171], p. 288). The metrics have been adapted from Besemer's Model for Creativity [171-173] and have been previously used in design research to assess design creativity [169, 174-178]. Additionally, we asked the raters to rate the drawing abilities possessed by each idea to control for that factor, since the drawing abilities have been found to influence ratings of creativity [179].

As per guidelines by Hennessey, Amabile, and Mueller's [180], experts were recruited to rate 20% of the complete idea set to provide a training set for quasi-experts to rate the remaining set based on the experts' mindset in rating the ideas [169, 181]. Two faculty members experienced in engineering design research independently rated 20% of the ideas. Additionally, two quasi-experts (PhD candidate and third-year undergraduate student, both studying Industrial Engineering) independently rated the 20% overlap of ideas to ensure agreement with the expert judges [154]. Each of the quasi-experts' ratings had high agreement ($\alpha > 0.75$) [182] with the expert raters on each of the five metrics. Once inter-rater reliability was achieved, as per guidelines by Hennessey, Amabile, and Mueller's [180], the two quasi-experts rated the remaining 80% of the ideas independently, and high interrater reliability ($\alpha > 0.75$) [182] was achieved between the two quasi-expert raters for each of the five metrics. An average of the scores from the two quasi-expert raters was calculated for each metric (overall creativity, elegance, usefulness, uniqueness, and drawing abilities), as per recommendations by Silvia [183], see Figure 5.2 for an example of a CAT rating.

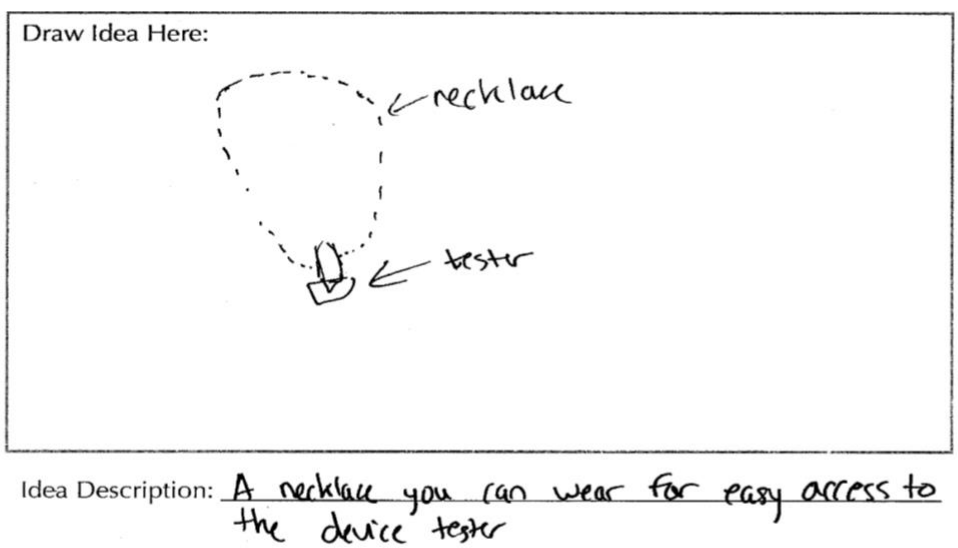

Figure 5.2 An idea from participant 53 that received a score of 4 on overall creativity, 3 on usefulness, 5 on uniqueness, 4 on elegance, and 3 on drawing abilities

***Propensity for Selecting Creative Ideas*:** To assess simulated teams' propensity for selecting creative concepts, we used the propensity toward creative concept selection metric, P_C [184], a metric that has been used in engineering design research [94, 184, 185]. Specifically, P_C measures the "…tendency towards selecting (or filtering) creative concepts during the concept selection process" ([184], p. 118). For instance, the formula to calculate participants' propensity towards selecting unique concepts ($P_{Uniqueness}$) can be summarized as the following:

$$P_{Uniqueness} = \frac{average\ uniqueness\ of\ selected\ concepts}{average\ uniqueness\ of\ generated\ concepts}$$

Similarly, an individual's propensity towards concept selection of ideas rated high in (1) overall creativity, (2) usefulness, (3) elegance, and (4) drawing abilities were also assessed in the same manner. For example, an individual can receive a value ($P_{Uniqueness}$) greater than 1 if the average uniqueness of the selected ideas is higher than the average uniqueness of the available ideas, indicating a propensity for selecting unique ideas, while a value on $P_{Uniqueness}$ that is less than 1 indicated an aversion for selecting unique concepts [184]. Toh and Miller's paper [184] provides further details on the scoring methodology.

5.5 Data Analysis and Results

In order to answer the research questions, statistical analyses were computed using SPSS 25.0, and a significance level of 0.05 was used in all analyses. The results are presented as mean ± standard deviation (SD) unless otherwise denoted. In addition, effect sizes were classified according to Cohen [186].

5.5.1 RQ1: Can trait empathy be used to predict the number of ideas generated in an engineering design project?

The first research question was devised to assess the impact of trait empathy on the number of ideas generated by participants. Based on prior research [53, 103, 187], we hypothesized that trait empathy would be positively related to the generation of more ideas. To answer this research question, a hierarchical regression model was computed, with the dependent variables being the number of ideas generated by each participant. In addition, since the design context, design problem, and course instructor have been shown to influence creativity [163, 188], we controlled for these factors as they were not the focus of the current investigation. To account for this, the independent variables were entered in two blocks: (i) design context (developing, developed), course instructor, and design problem, and (ii) perspective-taking, fantasy, empathic concern, personal distress. A visual schematic of the hierarchical regression analyses used for this RQ is shown in Figure 5.3.

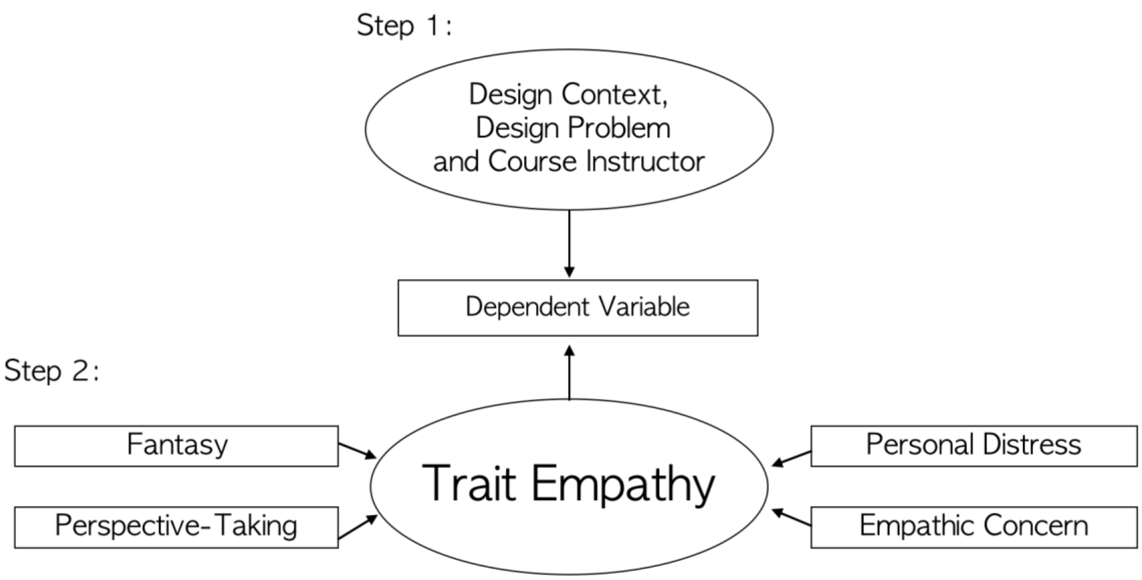

Figure 5.3 Schematic representation of the two-step hierarchical regression model for RQ1

Prior to the analysis, statistical assumptions were checked. The results showed the linearity of the independent variables as assessed by partial regression plots and a plot of studentized residuals against the predicted values. Visual inspection of a plot of studentized residuals revealed that the assumption of homoscedasticity was met. There was no multicollinearity in the independent variables, as assessed by tolerance values greater than 0.1 [189]. As assessed by the studentized deleted residuals greater than ±3 standard deviations, there were 4 outliers. The outliers were found to have no significant impact on the significance of the results, and therefore, the full analysis is presented here. Additionally, there were no leverage values greater than 0.2 [190], and no values for Cook's distance above 1 [191]. Finally, normality was confirmed by visually inspecting the histograms and Q-Q plots. Based on these results, the analysis proceeded as planned.

The results from the hierarchical regression model showed that the design context and problem, and the course instructor, significantly predicted the number of ideas, $R^2 = 0.124$, $F\ (3, 98) = 4.48$, $p < 0.01$, which is considered a small effect. However, the design context and problem, as well as the course instructor did not significantly contribute to the model, $p > 0.05$, see Table 5.1. The addition of trait empathy (fantasy, perspective-taking, personal distress, and empathic concern) to this model also led to a statistically significant model $F\ (7,98) = 2.99$, $p < 0.01$, with an R^2 change of 0.063. From the four empathic tendencies, *only* personal distress (p = 0.047) and empathic concern (p = 0.037) significantly contributed to the model. Specifically, personal distress negatively impacted the number of ideas generated by participants, while empathic concern positively impacted the number of ideas generated by participants.

Table 5.1 Summary statistics of the regression model on the relationship between the number of ideas and trait empathy

Step	Factor		*B*	*SE*	*β*	*p*
1	Context		1.664	1.058	-.029	.900
	Problem		-.204	1.612	-.002	.982
	Instructor		-.007	.320	.379	.119
2	Context		.559	1.640	.080	.734
	Problem		.041	.325	.014	.900
	Instructor		1.162	1.093	.264	.291
	Trait Empathy	Fantasy	-.005	.066	-.008	.945
		Personal Distress	-.139	.069	-.209	.047
		Perspective-Taking	-.108	.089	-.139	.227
		Empathic Concern	.169	.080	.242	.037

Note: B represents the unstandardized coefficient; SE represents the standard error associated with that coefficient; β is the standardized coefficient; p is the significance value associated with each factor

The findings from this research question partially support our hypothesis that trait empathy positively impacted the number of ideas generated during concept generation. Empathic concern positively impacted the number of ideas generated by participants. This finding partially corroborates a qualitative investigation with engineering students [55] that found that empathic concern tendencies motivated students to work harder on an engineering task. However, personal distress was found to impact the number of ideas generated by the participants, while perspective-taking and fantasy tendencies did not have an impact on the number of ideas generated ideas. This finding is congruent to the discussion in the literature that notes how being empathic may restrict the designer from coming up with creative innovations to the existing problem [81].

5.5.2 RQ2: Can trait empathy be used to predict the creativity of the ideas generated in an engineering design project?

While the first research question investigated the impact of trait empathy on the number of ideas generated by participants, the second research question was devised to assess whether participants' trait empathy predicted the overall creativity, elegance, usefulness, or uniqueness of the generated ideas. Based on prior research [53, 103, 187], we hypothesized that trait empathy would be positively related to the generation of ideas that are rated high in overall creative, elegant, useful, or unique ideas. To answer this research question, four hierarchical regression models were computed with the dependent variables being the average overall creativity, average elegance, average usefulness, and average uniqueness of the teams' generated ideas. In addition, since the design context, design problem, and course instructor have been shown to influence creativity [163, 188], we controlled for these factors as they were not the focus of the current investigation. Additionally, we controlled for the drawing abilities of each participant as the drawing abilities have been found to influence ratings of creativity [179]. To account for this, the independent variables were entered in two blocks: (i) participant's average drawing abilities, design context (developing, developed), course instructor, and design problem, and (ii) perspective-taking, fantasy, empathic concern, personal distress. A visual schematic of the hierarchical regression analyses used for this RQ is shown in Figure 5.4.

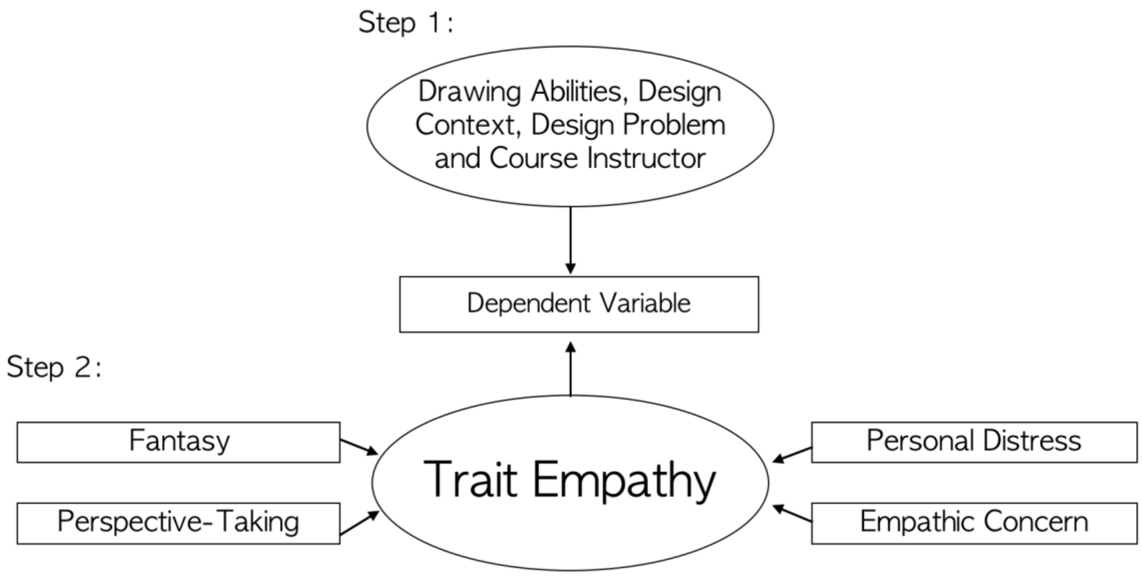

Figure 5.4 Schematic representation of the two-step hierarchical regression model for RQ2 and RQ3

Prior to the analysis, statistical assumptions were checked. The results showed the linearity of the independent variables as assessed by partial regression plots and a plot of studentized residuals against the predicted values. Visual inspection of a plot of studentized residuals revealed that the assumption of homoscedasticity was met. There was no multicollinearity in the independent variables, as assessed by tolerance values greater than 0.1 [189]. As assessed by the studentized deleted residuals greater than ±3 standard deviations, there were 0, 6, 4, and 1 outlier for the first, second, third, and fourth regression models, respectively. The outliers were found to have no significant impact on the significance of the results, and therefore, the full analysis is presented here. Additionally, there were no leverage values greater than 0.2 [190], and no values for Cook's distance above 1 [191]. Finally, normality was confirmed by visually inspecting the histograms and Q-Q plots. Based on these results, the analysis proceeded as planned.

The results from all four hierarchical regression models showed that participant's average drawing abilities, design context (developing, developed), course instructor, and design problem, and (ii) perspective-taking, fantasy, empathic concern, personal distress all did not significantly predict overall creativity, $p > 0.05$. These results indicated that trait empathy did not predict the overall creativity, usefulness, uniqueness, and elegance of the generated ideas.

The results from this research question refute our hypothesis that trait empathy would be related to creative idea generation. While the results from the first research question indicated that trait empathy predicted the number of ideas, it did not necessarily predict the creativity of those ideas. Specifically, all four empathic tendencies (perspective-taking, fantasy, empathic concern, personal distress) failed to predict the overall creativity, usefulness, uniqueness, and elegance of the generated ideas. These results resonate with prior work that discussed varying points of views [11, 12, 22] on the role of empathy in concept generations, whereby we find evidence that supports the notion of the utility of empathy on the number of ideas generated, but the null impact it had in terms of the creativity of those generated ideas.

5.5.3 RQ3: Can trait empathy be used to predict the propensity for selecting creative ideas in an engineering design project?

The third research question was devised to assess whether trait empathy impacted participants' propensity for selecting overall creative, elegant, useful, or unique ideas. Based on prior research [7, 64, 65], we hypothesized that trait empathy would be positively related to the selection of overall creative, elegant, useful, and unique ideas. To answer this research question, four hierarchical regression models were computed with the dependent variables being participants' propensity for selecting (1) overall creative, elegant, (2) useful, and (3) unique ideas. In addition, since the design context, design problem, and course instructor have been shown to influence creativity [163, 188], we controlled for these factors as they were not the focus of the current investigation. Additionally, we controlled for teams' propensity for selecting ideas that are rated high in drawing abilities since prior research found that the drawing abilities portrayed in a design could have a potential impact on an individual's perception of the creativity of that design [179]. To account for this, the independent variables were entered in two blocks: (i) the propensity for selecting ideas rated high in drawing abilities, design context (developing, developed), course instructor, and design problem, and (ii) trait empathy (perspective-taking, fantasy, empathic concern, personal distress). A visual schematic of the hierarchical regression analyses used for this RQ is shown in Figure 5.4.

Prior to the analysis, statistical assumptions were checked. The results showed the linearity of the independent variables as assessed by partial regression plots and a plot of studentized residuals against the predicted values. Visual inspection of a plot of studentized residuals revealed that the assumption of homoscedasticity was met. There was no multicollinearity in the independent variables, as assessed by tolerance values greater than 0.1 [189]. As assessed by the studentized deleted residuals greater than ±3 standard deviations, there were 4, 5, 3, and 3 outliers for the first, second, third, and fourth regression models, respectively. The outliers were found to have no significant impact on the significance of the results, and therefore, the full analysis is presented here. Additionally, there were no leverage values greater than 0.2 [190], and no values for Cook's distance above 1 [191]. Finally, normality was confirmed by visually inspecting the histograms and Q-Q plots. Based on these results, the analysis proceeded as planned.

The results from the first hierarchical regression model showed that only drawing abilities, but not design context and problem, nor the course instructor, significantly predicted the propensity for selecting **overall creative** ideas, $R^2 = 0.260$, $F(4, 89) = 8.34$, $p < 0.01$, which is considered a medium effect. The addition of trait empathy (fantasy, perspective-taking, personal distress, and empathic concern) to this model also led to a statistically significant model $F(8,89) = 4.51$, $p < 0.01$, with an R^2 change of 0.022; however, all of the perspective-taking, fantasy, empathic concern, personal distress, all did not contribute to the model, $p > 0.05$.

While the first regression model investigated the role of empathy on the propensity for selecting overall creative ideas, the second hierarchical regression model investigated the role of trait empathy on the propensity for selecting **elegant** ideas. The results from the second hierarchical regression model showed that only drawing abilities, but not design context and problem, nor the course instructor, significantly predicted the propensity for selecting **elegant** ideas, $R^2 = 0.345$, $F(4, 89) = 11.18$, $p < 0.01$, which is considered a medium effect. The addition of trait empathy (fantasy, perspective-taking, personal distress, and empathic concern) to this model also led to a statistically significant model $F(8,89) = 6.420$, $p < 0.01$, with an R^2 change of 0.043. Specifically, perspective-taking tendencies ($p = 0.027$) positively predicted participants' propensity for selecting elegant ideas. All other empathic tendencies did not significantly contribute to the model, see Table 5.2 for a summary of the regression statistics.

Table 5.2 Summary statistics of the regression model on the relationship between participants' propensity for selecting elegant ideas and trait empathy

Step	Factor		*B*	*SE*	*β*	*p*
1	Propensity for selecting ideas rated high in drawing abilities		.733	.118	6.228	<0.01*
	Context		.009	.078	.110	.913
	Problem		.001	.015	.040	.968
	Instructor		-.026	.051	-.496	.621
2	Propensity for selecting ideas rated high in drawing abilities		.750	.119	6.328	<0.01*
	Context		-.003	.078	-.041	.967
	Problem		.002	.015	.155	.877
	Instructor		-.028	.051	-.538	.592
	Trait Empathy	Fantasy	.002	.015	.155	.877
		Personal Distress	-.028	.051	-.538	.592
		Perspective-Taking	.009	.004	2.254	.027*
		Empathic Concern	.000	.003	.093	.926

Note: B represents the unstandardized coefficient; SE represents the standard error associated with that coefficient; β is the standardized coefficient; p is the significance value associated with each factor

The results from the third hierarchical regression model showed that the design context and problem, and the course instructor, significantly predicted the **usefulness** of the generated ideas, $R_2 = 0.599$, $F\ (4,89) = 31.77$, $p < 0.01$, which is considered a large effect. However, the design context and problem, as well as the course instructor, did not significantly contribute to the model, p > 0.05. The addition of trait empathy (fantasy, perspective-taking, personal distress, and empathic concern) to this model also led to a statistically significant model $F(8,89) = 16.82$, $p < 0.01$, with an R_2 change of 0.025; however, all of the four empathic tendencies, fantasy, perspective-taking, personal distress, and empathic concern, did not significantly contribute to the model, p > 0.05.

Finally, the fourth hierarchical regression model investigated the role of trait empathy on the propensity for selecting **unique** ideas. The results from the fourth hierarchical regression model showed that the design context and problem, and the course instructor, significantly predicted participants' propensity for selecting **unique** ideas, $R_2 = 0.179$, $F(4,89) = 4.62$, $p < 0.01$, which is considered a small effect. However, the design context and problem, as well as the course instructor, did not significantly contribute to the model, $p > 0.05$. The addition of trait empathy (fantasy, perspective-taking, personal distress, and empathic concern) to this model also led to a statistically significant model $F(8,89) = 2.82$, $p < 0.01$, with an R_2 change of 0.039; however, all of the four empathic tendencies, fantasy, perspective-taking, personal distress, and empathic concern, did not significantly contribute to the model, $p > 0.05$.

The findings from the third research question partially support our hypotheses that trait empathy predicted creative concept selection. Specifically, perspective-taking tendencies positively predicted participants' propensity for selecting elegant ideas. These results confirm previous work that highlighted the significance of perspective-taking tendencies in an engineering context [53, 188]. However, perspective-taking tendencies were only impactful for selecting elegant ideas, and not ideas rated high in overall creativity, usefulness, and uniqueness. Additionally, all of the other empathic tendencies, fantasy, empathic concern, and personal distress, had no significant impact on creative concept selection.

5.6 Discussion

The main goal of this paper was to explore the role of team empathy in concept generation and selection. The main findings from the study are as follows:

- Empathic concern tendencies positively predicted the generation of more ideas while personal distress tendencies negatively predicted the generation of more ideas.
- Perspective-taking tendencies positively predicted participants' propensity for selecting elegant ideas.

These main findings are discussed below with respect to our research questions.

5.6.1 The role of empathy in concept generation

The first finding from this study indicated that while trait empathy impacted the number of ideas generated by participants, it did not necessarily impact the creativity of those ideas. The components of trait empathy studied in this chapter are perspective-taking, empathic concern, personal distress, and fantasy. Specifically, the results indicated that empathic concern tendencies positively predicted the generation of more ideas. This finding partially corroborates a qualitative investigation with engineering students [55] that found that empathic concern tendencies motivated students to work harder on an engineering task. Meanwhile, personal distress tendencies negatively predicted the generation of more ideas. This relates to findings in the literature that notes how being empathic may restrict the designer from coming up with creative innovations to the existing problem [81], commonly referred to as the empathy trap [21, 22]. Similarly, Breithaupt [22] refers to this form of empathy as empathic vampirism, suggesting that the designer would end up designing for themselves if they over empathize [21]. While different components of trait empathy had both a positive and negative impact on the number of ideas generated, the results found that trait empathy did not impact the creativity (overall creativity, usefulness, uniqueness, and elegance) of those ideas. Taken as a whole, these results resonate with the discussion in the literature that displays varying points of views on the role of empathy in concept generation [11, 12, 22].

5.6.2 The role of empathy in concept selection

While the results from concept generation indicated that trait empathy did not impact the creativity of the ideas, the findings from concept selection indicated that trait empathy did impact the propensity for selecting elegant ideas. Specifically, perspective-taking tendencies positively predicted participants' propensity for selecting elegant ideas. These results underline previous work that highlights the importance of perspective-taking tendencies in engineering contexts [53, 188]. However, those results were only true for selecting elegant ideas, and not for selecting ideas rated high in overall creativity, usefulness, and uniqueness. Overall, the results from this study confirmed prior work that discussed varying points of views [11, 12, 22] on the role of empathy in design, whereby we find evidence that supports the notion of the utility of empathy and the negative impact of empathy in both the concept generation and selection stages of the design process.

Since the design community has become invested in devising empathy-invoking interventions [13, 20], the results from this research call for the need to prepare *specific* interventions that trigger certain types of empathic tendencies. This is in line with prior work in psychology that suggests the importance of triggering interventions targeted towards specific components of empathy [192]. Specifically, these results indicated that interventions geared at empathic concern tendencies are favorable during concept generation while the design community should refrain from evoking personal distress tendencies during concept generation. Meanwhile, during concept selection, our results suggest the value of triggering perspective-taking tendencies to allow designers to select elegant ideas. While the results from this chapter established the relationship between trait empathy and creative design outcomes, it warrants future research that could capture students' motivation throughout these tasks as motivation could be a mediator factor to students' empathy [55, 193] and creativity [86] by impacting their attitudinal stance toward the design task.

5.7 Conclusions and future work

The main goal of this study was to explore the role of trait empathy on concept generation and selection in an engineering design student project. Formalizing the role of trait empathy in the concept generation and selection stages is important because the success and final cost of a product can be linked to the early conceptual stages of the idea's emergence [10, 37], and being empathic in those stages *could* be the gateway to creative solutions to a design problem [7]. Thus, this research provides clarity to the existing literature by explaining *if*, *when*, or *how* empathy impacts creative design outcomes in the concept generation and selection stages of the design process. The main findings from this research highlighted that empathic concern tendencies positively impacted the generation of more ideas, while personal distress tendencies negatively impacted the generation of more ideas. During concept selection, perspective-taking tendencies positively impacted participants' propensity for selecting elegant ideas. These results highlight the complicated nature of the role of empathy in design and confirms prior research on the varying roles of empathy in the design process.

However, there are several limitations that need to be identified that could lead to interesting avenues for future research. While this work started exploring the relationship between trait empathy and creative concept generation and selection, future research should assess the relationship of trait empathy with other design outcomes, such as the quality of the final design. Moreover, while this research explored the utility of empathy in humanitarian engineering problems, future research is needed to extend these results with other engineering design tasks. Finally, while prior research found that the ideation patterns of first-year and senior-level students differ [52], this work only studied first-year students. Thus, future research is warranted to extend those findings beyond first-year students.

CHAPTER 6

CAN DESIGN TEAMS BE EMPATHICALLY CREATIVE? A SIMULATION-BASED INVESTIGATION ON THE ROLE OF TEAM EMPATHY ON CONCEPT GENERATION AND SELECTION

The paper presented in this chapter is based on a conference paper accepted for publication in the proceedings of the 2020 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference [194]. The extension of this conference paper presented in this chapter is based on work to be submitted for publication to the Journal of Mechanical Design in June 2020. This work is multiple-authored by Mohammad Alsager Alzayed, Dr. Christopher McComb, Dr. Jessica Menold, Jacquelyn Huff, and Dr. Scarlett Miller. Mohammad Alsager Alzayed is the lead author on the paper, and Dr. Scarlett Miller and Dr. Christopher McComb helped advise this work.

6.1 Abstract

While Chapter 5 of this dissertation focused on investigating the role of students' empathy in the concept generation and selection stages of the design process, it has been primarily limited to *individuals*, meaning we do not know how it impacts *team* performance, particularly in the concept generation and selection stages of the design process. Specifically, it is unknown how the empathic composition of teams, average (elevation) and standard deviation (diversity) of team members' empathy, would impact design outcomes in the concept generation and selection stages of the design process. This is problematic because teamwork is an essential component of

engineering design education [29-31], due to its ability to promote peer learning, problem solving, and the exploration of the solution space.

Therefore, the goal of the study presented in Chapter 6 was to investigate the impact of team empathy on concept generation and selection in an engineering design student project. This was accomplished through a computational simulation of 13,482 teams of noninteracting brainstorming individuals generated by a statistical bootstrapping technique drawing upon a design repository of 806 ideas generated by the first-year engineering students that participated in the empirical study. The main findings from the study indicated that the utility of the elevation and diversity of different types of team empathy varied depending upon the specific design outcome (overall creativity, elegance, usefulness, uniqueness) and design stage (concept generation and selection). The results from this study can be used to guide team formation in engineering design education.

6.2 Introduction

Empathy, or "the reactions of one individual to the observed experiences of another" ([5], p. 113), has been viewed as an essential component of the design process due to its ability to help designers "relate to [the user] and understand the situations and why certain experiences are meaningful to these [users]" ([8], p. 67). As such, engineering researchers have invested substantial time and effort to studying the impact of empathic design experiences [20, 53, 56, 71, 73, 74], such as simulating empathy-evoking scenarios [13, 20], in the engineering design process. This line of research has shown that empathic design experiences can help designers generate ideas that are of high quality [12], novelty [11], and variety [11].

However, research on empathy has been primarily limited to individuals, meaning we do not know how empathy impacts team performance. This is problematic because teamwork is an essential component of engineering design [29-31], due to its ability to promote peer-learning [88], problem solving [32] and improve the exploration of the solution space [33-35]. By extrapolating the results from the research on empathy on individuals, the social dynamics and non-summative effects from teamwork might not be captured [122]. As such, investigating the impact of *team* *empathy* on engineering design outcomes is warranted. Specifically, it is unknown how the empathic composition of teams would impact design outcomes in the earlier stages (i.e., concept generation and selection [6]) of the design process. Formalizing the role of team empathy in the earlier stages of the design process is important because the success and final cost of a product can be linked to the early conceptual stages of the idea's emergence [10, 37], and being empathic in those early stages *could* be design team's gateway to creative solutions to a design problem [7]. Studying empathy in a team setting is of particular importance in this chapter due to the belief that a team of designers *could* have the ability to come up with more creative solutions than individual designers alone [195, 196]. However, without clarifying the role of *team* empathy in design, it is unknown *if*, *when*, and *how* empathy is important in promoting creative design outcomes.

Currently, the engineering design literature provides conflicting interpretations of the role of empathy in the concept generation stage of the design process. For instance, Genco et al. [12] and Johnson et al. [11] found that simulating empathy-evoking scenarios helped designers generate ideas that are of high quality [12], novelty [11], and variety [11]. However, other researchers have identified a dark side to empathy, referred to as empathic vampirism [21, 22], where designers' empathy would allow them to over-identify with the end-users, resulting in poor design outcomes [21].

While prior research has explored the varying roles of empathy in concept generation, the role of empathy in driving creative concept *selection* has been scarcely researched. This is problematic since generating creative ideas does not necessarily guarantee the final design's creativity [23, 24], as the "availability of creative ideas is a necessary but insufficient condition for innovation" ([25], p. 48). Clarifying the role of empathy during the concept selection stage is critical due to the importance of the concept selection stage in driving successful engineering design [26-28].

Therefore, the objective of this paper was to explore the impact of team empathy on concept generation and selection in an engineering design student project. This paper sought to study the average (elevation [36]) and standard deviation (diversity [36]) of team trait empathy. Computing the average and standard deviation of individual attributes to represent team-level constructs is derived from research practices in the psychology literature (e.g., [36], [92] and [93]). Overall, the research presented in this chapter is one of the first to study empathy on a team level and would provide one of the first evidence on the empathic composition of engineering design teams.

6.3 Research Objectives

Based on this prior work, the objective of this paper was to explore the impact of team empathy on concept generation and selection. This paper sought to study the elevation (average [36]) and diversity (standard deviation [36]) of team trait empathy. Specifically, the paper was developed to answer the following research questions (RQ):

RQ1: Can the elevation or diversity of team trait empathy be used to predict a team's number of generated ideas? We hypothesized that team trait empathy *elevation* would be positively related to the generation of more ideas due to prior work with engineering graduate students that found that trait empathy was related to their innovative self-efficacy [53]. It was also hypothesized that team empathy *diversity* would be positively related to the number of ideas generated since prior research has reported that diversity could be a mediator to successful team outcomes [103, 187].

RQ2: Can the elevation or diversity of team trait empathy be used to predict a team's ability to generate creative ideas? We hypothesized that team trait empathy *elevation* would be positively related to the generation of creative ideas due to prior work with engineering graduate students that found that trait empathy was related to their innovative self-efficacy [53]. It was also hypothesized that team empathy *diversity* would be positively related to the teams' elegant, useful, and unique idea generation since prior research has reported that diversity could be a mediator to successful team outcomes [103, 187].

RQ3: Can the elevation or diversity of team empathy be used to predict a team's propensity for selecting creative ideas? We hypothesized that team trait empathy *elevation* would be positively related to the selection of creative ideas due to prior work with engineering graduate students that found that trait empathy was related to their innovative self-efficacy [53]. It was also hypothesized that team empathy *diversity* would be positively related to the teams' selection of elegant, useful, and unique ideas since prior research has reported that diversity could be a mediator to successful team outcomes [103, 187].

6.4 Methodology

In order to answer these research questions, a study was conducted with 103 first-year engineering design students who were in four sections of an introduction to engineering design course taught by three instructors at a large Northeastern university. Specifically, 103 first-year engineering design students (73 men and 30 women) from four different sections of a cornerstone engineering course participated in an 8-week design project that focused on "ensuring healthy lives and promoting well-being for all at all ages." ([197], p. 8). Teams were asked to select between the following challenges: (1) lack of safe water, sanitation, and hygiene services, (2) access to vaccinations, (3) indoor and ambient air pollution, and (4) road traffic injuries [125, 163, 188], see [126] for the complete problem statements. While teams were allowed to select from these four design challenges, the design context of these challenges was different across the course sections; two of the sections focused on designing for the *developed* world (n = 50 participants) while the remaining two sections focused on designing for the *developing* world (n = 53 participants) [125, 126, 163, 188]. Chapter 3 provides a detailed explanation of the data collection procedure, and Figure 6.1 provides a summary of the activities during the project.

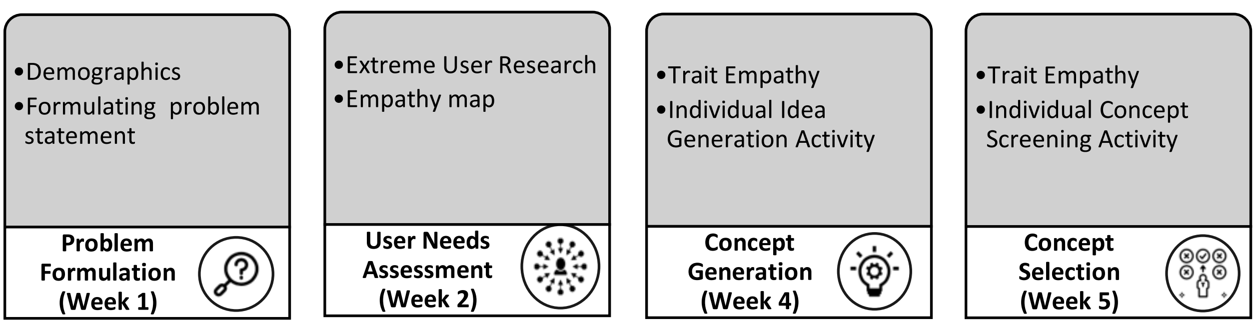

Figure 6.1 Timeline of the project

Of importance to the study presented in this chapter, participants were involved in concept generation and concept selection activities. Specifically, during the concept generation stage (week 4), participants were involved in two brainstorming sessions: reverse brainstorming [130], where they were given 15 minutes to brainstorm bad ideas that would make the problem worse, and then individual brainstorming where they were asked to generate concepts for 20 minutes. During the concept selection stage (week 5), participants were asked to select concepts using a concept screening matrix. Participants were asked to complete the Trait Empathy survey at the end of week 4, immediately after the concept generation activity, and at the end of week 5, immediately after the concept selection activity.

Since user studies are time consuming and potentially costly, a computational simulation was used in the current dissertation to investigate the role of the empathic composition of teams on design outcomes. Prior work has shown that computational simulations are an effective means of exploring characteristics of human teams [108, 109]. For instance, computational simulations have been used to successfully generate nominal problem-solving teams [108]. The simulation model used in this study involved the use of nominal brainstorming teams, where individuals first generate ideas individually, and then the ideas are pooled together as a team [110-113].

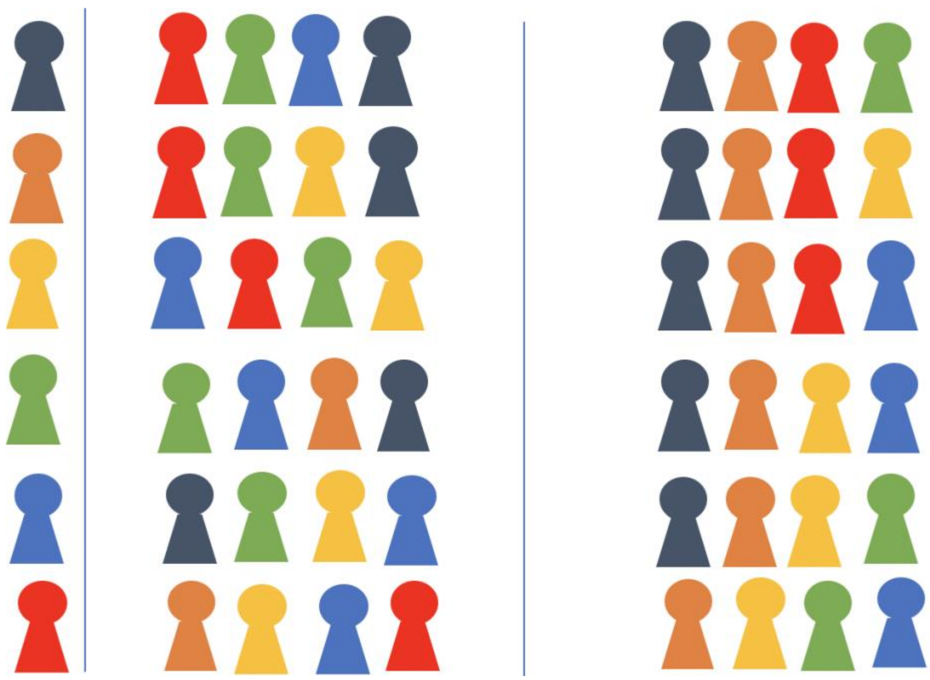

Figure 6.2 An example of all possible computationally simulated teams from 6 individuals

The data set for the simulation was derived from the study conducted with the 103 first-year engineering students described in section 3.2. Specifically, from the 103 participants, all possible combinations of four-person teams were simulated. The simulation setup controlled for instructor, design context and design problem. In other words, participants from different design problems, contexts, or instructors were not mixed in the same team, see Table 6.1 for a summary of the

13,482 possible team combinations included in the simulation. Each of the 9 team types in Table 6.1 included different combinations of all participants to get every combination with replacement; a similar methodology has been implemented by engineering design researchers to generate nominal problem-solving teams in previous studies [105-108]. Specifically, the computational simulation was based on a probabilistic event. While every possible combination of team member type (see table 6.1) was considered, each type can be satisfied by a number of different participants in the dataset. The selection of those participants to form the simulation teams is thus randomized. This technique closely relates to the statistical bootstrapping technique [119], which has been employed by Wright [120] to create nominal groups, see Figure 6.2 for an example of a computational simulation.

Table 6.1 Number of simulated teams

Team Type	Design Problem	Course Instructor	Design Context	Number of participants	Number of teams
1	Water Sanitation	1	Developed	22	7315
-		2	Developing	0	-
2		3		19	3876
3	Vaccination Access	1	Developed	7	35
-		2	Developing	0	-
-		3		0	-
4	Air Pollution	1	Developed	13	715
5		2	Developing	15	1365
6		3		7	35
7	Traffic Injuries	1	Developed	8	70
8		2	Developing	8	70
9		3		4	1
Total number of teams					13,482

6.4.1 Data Collection Instruments and Metrics

In order to explore the factors critical to achieving the research objectives, the following instruments were used:

Trait Empathy*:* Participants' trait empathy was measured using the IRI [48], a 28-item survey answered on a 5-point Likert scale ranging from "does not describe me well" to "describes me very well." The IRI includes 4 subscales (perspective taking, fantasy, empathic concern, and personal distress), each made up of 7 different items. Due to previous research that shows that trait empathy changes between the design stages (concept generation, concept selection) [188], we have tested the hypotheses with participants' empathy at those different time points. Further details on the IRI scoring methodology can be found in section 3.3 of the dissertation.

To measure trait empathy for each of the 13,482 simulated teams, both team empathy elevation and team empathy diversity were considered. Team empathy elevation takes the average across all team members' trait empathy scores for each subscale (fantasy, personal distress, perspective-taking, and empathic concern) while team empathy diversity takes the standard deviation in team members' trait empathy scores for each subscale. Studying both the team's elevation and diversity is important since previous research has found that both of those metrics predicted team performance in engineering [95].

Consensual Assessment Technique (CAT)**:** The Consensual Assessment Technique [165] was used to assess the effectiveness of the ideas generated by the 103 participants. Section 5.4.1 discusses the specifics of how the ideas were rated. To obtain a score on overall creativity, uniqueness, usefulness, elegance, and drawing abilities for each simulated *team*, an average score across all team members is taken for each of the metrics.

Propensity for Selecting Creative Ideas**:** To assess simulated teams' propensity for selecting creative concepts, we used the propensity toward creative concept selection metric, P_C [184], a metric that has been used in engineering design research [94, 184, 185]. Specifically, P_C measures the "…tendency towards selecting (or filtering) creative concepts during the concept selection process" ([184], p. 118). Section 5.4.1 discusses the specifics of how this metric is calculated.

It is important to mention that concept selection itself is not simulated in each team simulation. Rather, we calculate the average team members' propensity for selecting useful, unique, and elegant ideas. These ideas come from the original dataset from their respective teams, see Chapter 3. To obtain $P_{Overall\ Creativity}$, $P_{Uniqueness}$, $P_{Usefulness}$, $P_{Elegance}$, and $P_{Drawing\ abilities}$ scores for each simulated team, an average score across all team members is taken for each of the four metrics.

6.5 Data Analysis and Results

In order to answer the research questions, statistical analyses were computed using SPSS 25.0, and a significance level of 0.05 was used in all analyses. The results are presented as mean ± standard deviation (SD) unless otherwise denoted. In addition, effect sizes were classified according to Cohen [186]. Finally, as a reminder, elevation relates to the average scores of the team [36], while diversity relates to the standard deviation of the team [36] for each attribute.

6.5.1 RQ1: Can the elevation or diversity of team trait empathy be used to predict the number of ideas generated by a team?

The first research question was devised to assess the impact of trait empathy elevation and diversity on the number of ideas generated by simulated teams. Based on prior research [53, 103, 187], we hypothesized that trait empathy would be positively related to the number of ideas generated by a team. To answer this research question, a hierarchical regression model was computed with the dependent variables being the number of ideas generated by each team. In addition, since the design context, design problem, and course instructor have been shown to influence creativity [163, 188], we controlled for these factors as they were not the focus of the current investigation. To account for this, the independent variables were entered in two blocks: (i) design context (developing, developed), course instructor, and design problem, and (ii) team empathy elevation and team empathy diversity. A visual schematic of the hierarchical regression analyses used for this RQ is shown in Figure 6.3

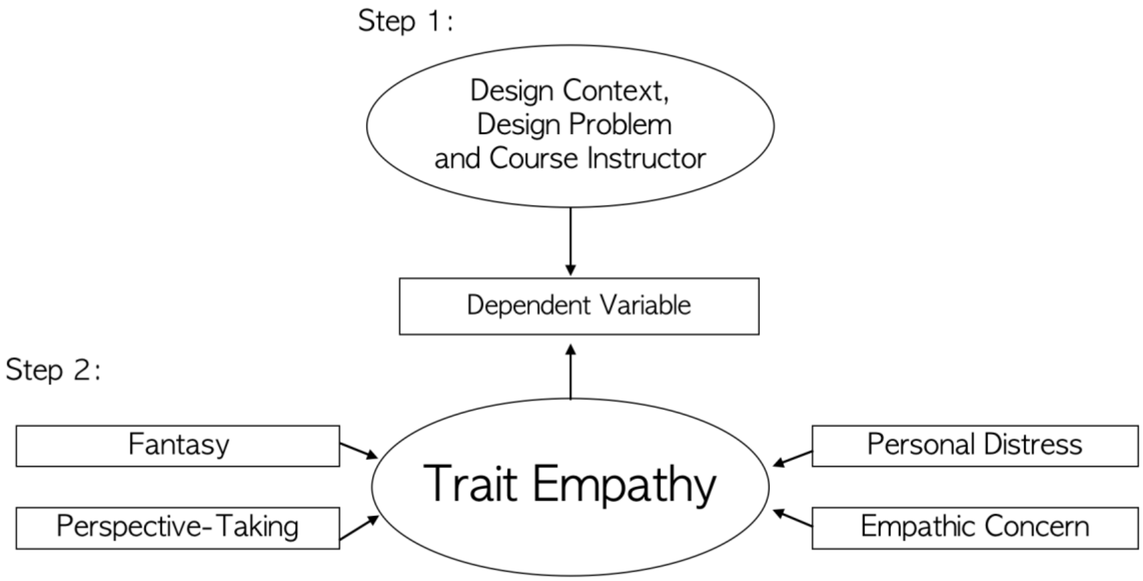

Figure 6.3 Schematic representation of the two-step hierarchical regression model for RQ1

Prior to the analysis, statistical assumptions were checked. The results showed the linearity of the independent variables as assessed by partial regression plots and a plot of studentized residuals against the predicted values. Visual inspection of a plot of studentized residuals revealed that the assumption of homoscedasticity was met. There was no multicollinearity in the independent variables, as assessed by tolerance values greater than 0.1 [189]. As assessed by the studentized deleted residuals greater than ±3 standard deviations, there were 27 outliers. The outliers were found to have no significant impact on the significance of the results, and therefore, the full analysis is presented here. Additionally, there were no leverage values greater than 0.2 [190], and no values for Cook's distance above 1 [191]. Finally, normality was confirmed by visually inspecting the histograms and Q-Q plots. Based on these results, the analysis proceeded as planned.

The results from the hierarchical regression model showed that the design context and problem, and the course instructor, significantly predicted the number of ideas, $R^2 = 0.287$, F (4,13481) = 1804.75, $p < 0.01$, which is considered a medium effect. However, the design context and problem, as well as the course instructor did not significantly contribute to the model, $p > 0.05$, see Appendix C for summary statistics of the regression model. The addition of trait empathy (fantasy, perspective-taking, personal distress, and empathic concern) elevation and diversity to this model also led to a statistically significant model F (12,13481) = 731.82, $p < 0.01$, with an R^2 change of 0.087. Specifically, simulated teams' elevation in empathic concern and fantasy positively impacted the number of ideas generated, while the elevation in personal distress and perspective-taking negatively impacted the number of ideas generated. Meanwhile, the diversity in fantasy had a positive impact on the number of ideas generated while the diversity in personal distress negatively impacted the number of generated ideas; the diversity in perspective-taking and empathic concern had no significant impact.

The findings from this research question partially support our hypothesis that trait empathy positively impacted the number of ideas generated during concept generation. This finding is congruent to the discussion in the literature that note the varying points of view on the role of empathy [11, 12, 22], whereby we find evidence that supports the notion that the influence of the elevation and diversity of empathy differs amongst the different empathic tendencies (perspective-taking, fantasy, empathic concern, and personal distress).

6.5.2 RQ2: Can the elevation or diversity of team trait empathy be used to predict a team's ability to generate creative ideas?

The second research question was devised to assess whether the elevation and diversity of simulated teams' trait empathy predicted their ability to generate overall creative, elegant, useful, or unique ideas. Based on prior research [53, 103, 187], we hypothesized that team trait empathy elevation and diversity would be positively related to the generation of overall creative, elegant, useful, or unique ideas. To answer this research question, four hierarchical regression models were computed with the dependent variables being the average overall creativity, average elegance, average usefulness, and average uniqueness of the teams' generated ideas. In addition, since the design context, design problem, and course instructor have been shown to influence creativity [163, 188], we controlled for these factors as they were not the focus of the current investigation. Additionally, we controlled for the drawing abilities of each simulated team as the drawing abilities have been found to influence ratings of creativity. To account for this, the independent variables were entered in two blocks: (i) teams' average drawing abilities, design context (developing, developed), course instructor, and design problem, and (ii) team empathy elevation and team empathy diversity. A visual schematic of the hierarchical regression analyses used for this RQ is shown in Figure 6.4.

Prior to the analysis, statistical assumptions were checked. The results showed the linearity of the independent variables as assessed by partial regression plots and a plot of studentized residuals against the predicted values. Visual inspection of a plot of studentized residuals revealed that the assumption of homoscedasticity was met. There was no multicollinearity in the independent variables, as assessed by tolerance values greater than 0.1 [189]. As assessed by the studentized deleted residuals greater than ±3 standard deviations, there were 26, 33, 87, and 81 outliers for the first, second, third, and fourth regression models, respectively. The outliers were found to have no significant impact on the significance of the results, and therefore, the full analysis is presented here. Additionally, there were no leverage values greater than 0.2 [190], and no values for Cook's distance above 1 [191]. Finally, normality was confirmed by visually inspecting the histograms and Q-Q plots. Based on these results, the analysis proceeded as planned.

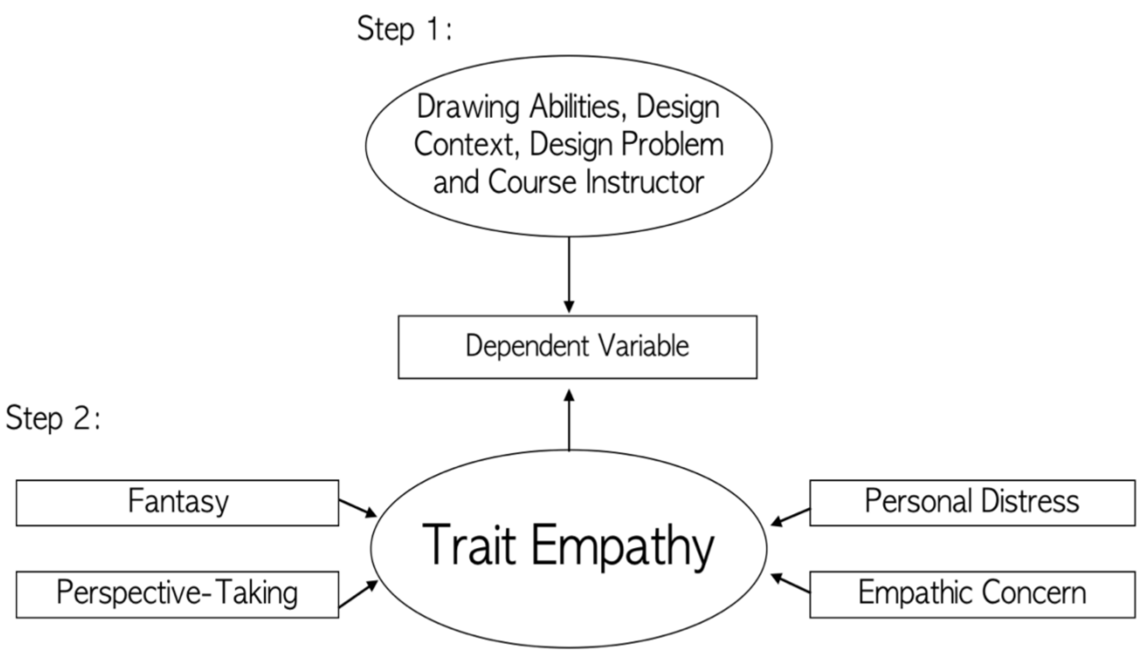

Figure 6.4 Schematic representation of the two-step hierarchical regression model for RQ2 and RQ3

The results from the first hierarchical regression model showed that team drawing abilities, design context and problem, as well as the course instructor, significantly predicted the average **overall creativity** of the ideas generated by simulated teams, $R^2 = 0.346$, $F(4, 13481) = 1781.482$, $p < 0.01$, which is considered a medium effect. The addition of team empathy elevation and team empathy diversity to this model also led to a statistically significant model $F(12,13481) = 675.714$, $p < 0.01$, with an R^2 change of 0.030, see Figure 6.5 for a summary of the contributing factors and the Appendix C for summary statistics of the regression model. Specifically, simulated teams' elevation in fantasy, perspective-taking, personal distress, and empathic concern positively impacted the average overall creativity of the ideas generated. Meanwhile, the diversity in personal distress and perspective-taking negatively impacted the overall creativity of teams' ideas, while the diversity in fantasy and empathic concern had no significant impact.

While the first regression model investigated the role of team empathy elevation and diversity on the average overall creativity of ideas, the second hierarchical regression model investigated the role of trait empathy elevation and diversity on the average **elegance** of generated ideas. The results from the second hierarchical regression model showed that the team drawing abilities, design context and problem, as well as the course instructor, significantly predicted the average **elegance** of the ideas generated by simulated teams, $R^2 = 0.169$, $F(4, 13481) = 686.290$, $p < 0.01$, which is considered a small effect. The addition of the team empathy elevation and diversity to this model also led to a statistically significant model, $F(12,13481) = 292.083$, $p < 0.01$, with an R^2 change of 0.037, see Figure 6.5 for a summary of the contributing factors and the Appendix C for summary statistics of the regression model. Specifically, simulated teams' elevation in empathic concern positively impacted the average elegance of the ideas generated while fantasy, perspective-taking, and personal distress had a negative impact. Meanwhile, the diversity in personal distress and perspective-taking positively impacted the overall creativity of teams' ideas, while the diversity in fantasy and empathic concern had no significant impact.

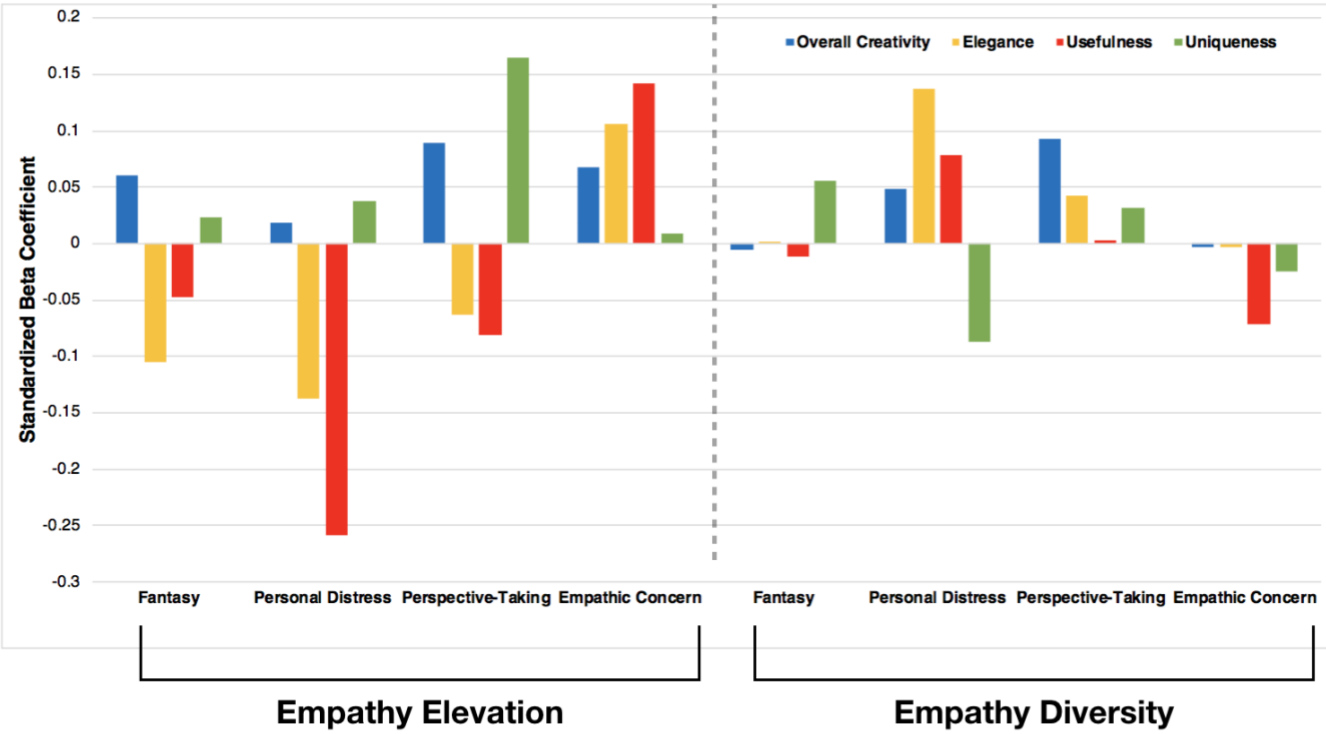

Figure 6.5 Standardized beta coefficients of the statistically significant predictors from the four regression models displaying the relationship between the average overall creativity, elegance, usefulness, uniqueness of generated ideas and the elevation and diversity in each of the four trait empathy subscales

The third hierarchical regression model investigated the role of trait empathy elevation and diversity on the average **usefulness** of generated ideas. The results from the third hierarchical regression model showed that the design context and problem, as well as the course instructor, significantly predicted the average **usefulness** of the ideas generated by simulated teams, $R^2 = 0.281$, $F\ (4,\ 13481) = 1315.951$, $p < 0.01$, which is considered a medium effect. The addition of team empathy elevation and diversity to this model also led to a statistically significant model, $F\ (12,13481) = 576.999$, $p < 0.01$, with an R^2 change of 0.059, see Figure 6.5 for a summary of the contributing factors and the Appendix C for summary statistics of the regression model. Specifically, simulated teams' elevation in empathic concern positively impacted the average usefulness of the ideas generated while fantasy, perspective-taking, and personal distress had a negative impact. Meanwhile, the diversity in personal distress positively impacted the usefulness of teams' ideas, while the diversity in empathic concern had a negative impact; fantasy and perspective-taking had no impact on the usefulness of teams' ideas.

Finally, the results from the fourth hierarchical regression model showed that team drawing abilities, design context and problem, as well as the course instructor, significantly predicted the average **uniqueness** of the ideas generated by simulated teams, $R^2 = 0.522$, $F(4, 13481) = 3680.821$, $p < 0.01$, which is considered a large effect. The addition of team empathy elevation and team empathy diversity to this model also led to a statistically significant model $F(12,13481) = 1346.902$, $p < 0.01$, with an R^2 change of 0.023, see Figure 6.5 for a summary of the contributing factors and the Appendix C for summary statistics of the regression model. Specifically, simulated teams' elevation in fantasy, perspective-taking, and personal distress positively impacted the average uniqueness generated by teams, while empathic concern had no significant impact. Meanwhile, the diversity in fantasy and perspective-taking positively impacted the uniqueness of teams' ideas, while the diversity in personal distress and empathic concern had the opposite effect. The effect size of the overall model was considered large.

The results from this research question partially support our hypothesis that team empathy elevation positively predicted simulated teams' ability to generate overall creative, elegant, useful, or unique ideas. These results are similar in nature to the results from RQ1, whereby the influence of the elevation and diversity of empathy on creative concept generations differs amongst the different empathic tendencies (perspective-taking, fantasy, empathic concern, and personal distress). These results highlight the complicated nature of empathy in design and call against a one-size fits all view of empathy in design.

6.5.3 RQ3: Can the elevation or diversity of team empathy be used to predict a team's propensity for selecting creative ideas?

The third research question was devised to assess whether the elevation and diversity of simulated teams' trait empathy predicted their selection of overall creative, elegant, useful, or unique ideas. Based on prior research [7, 64, 65], we hypothesized that team trait empathy elevation and diversity would be positively related to the selection of overall creative, elegant, useful, and unique ideas. To answer this research question, four hierarchical regression models were computed with the dependent variables being the teams' propensity for selecting (1) overall creative, elegant, (2) useful, and (3) unique ideas. In addition, since the design context, design problem, and course instructor have been shown to influence creativity [163, 188], we controlled for these factors as they were not the focus of the current investigation. Additionally, we controlled for teams' propensity for selecting ideas that are rated high in drawing abilities since a preliminary analysis found that it had an impact on teams' propensity for selecting overall creative, elegant, useful, or unique ideas. To account for this, the independent variables were entered in two blocks: (i) teams' propensity for selecting ideas rated high in drawing abilities, design context (developing, developed), course instructor, and design problem, and (ii) team empathy elevation and team empathy diversity. A visual schematic of the hierarchical regression analyses used for this RQ is shown in Figure 6.4.

Prior to the analysis, statistical assumptions were checked. The results showed the linearity of the independent variables as assessed by partial regression plots and a plot of studentized residuals against the predicted values. Visual inspection of a plot of studentized residuals revealed that the assumption of homoscedasticity was met. There was no multicollinearity in the independent variables, as assessed by tolerance values greater than 0.1 [189]. As assessed by the studentized deleted residuals greater than ±3 standard deviations, there were 63, 60, 61, and 191 outliers for the first, second, third, and fourth regression models, respectively. The outliers were found to have no significant impact on the significance of the results, and therefore, the full analysis is presented here. Additionally, there were no leverage values greater than 0.2 [190], and no values for Cook's distance above 1 [191]. Finally, normality was confirmed by visually inspecting the histograms and Q-Q plots. Based on these results, the analysis proceeded as planned.

The results from the first hierarchical regression model showed that team's propensity for selecting ideas rated high in drawing abilities, design context and problem, as well as the course instructor, significantly predicted simulated teams' propensity for selecting **overall creative ideas**, $R^2 = 0.154$, $F(4, 13480) = 614.180$, $p < 0.01$, which is considered a medium effect. The addition of team empathy elevation and team empathy diversity to this model also led to a statistically significant model $F(12,13480) = 259.460$, $p < 0.01$, with an R^2 change of 0.034, see

Figure 6.6 for a summary of the contributing factors and the Appendix C for summary statistics of the regression model. Specifically, simulated teams' elevation in empathic concern positively impacted the propensity for selecting overall creative ideas while fantasy, perspective-taking, and personal distress had a negative impact. Meanwhile, the diversity in fantasy positively impacted the propensity for selecting overall creative ideas, while the diversity in personal distress and empathic concern had a negative impact; the diversity in perspective-taking had no significant impact.

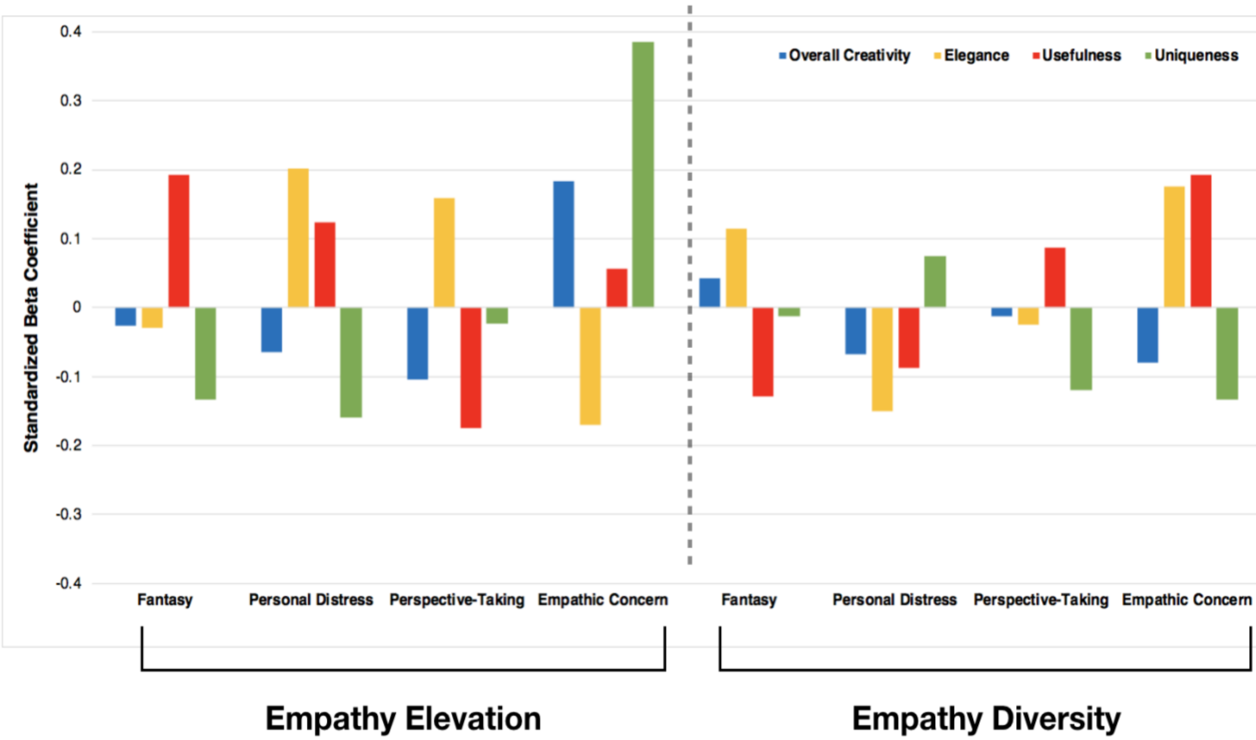

Figure 6.6 Standardized beta coefficients of the statistically significant predictors from the four regression models displaying the relationship between the propensity for selecting overall creative, elegant, useful, and unique ideas and the elevation and diversity in each of the four trait empathy subscales

While the first regression model investigated the role of team empathy elevation and diversity on the propensity for selecting overall creative ideas, the second hierarchical regression model investigated the role of team empathy elevation and diversity on the propensity for selecting **elegant** ideas. The results from the second hierarchical regression model showed that team's propensity for selecting ideas rated high in drawing abilities, design context and problem, as well as the course instructor, significantly predicted simulated teams' propensity for selecting **elegant ideas**, $R^2 = 0.193$, $F(4, 13480) = 803.391$, $p < 0.01$, which is considered a small effect. The addition of team empathy elevation and team empathy diversity to this model also led to a statistically significant model $F(12,13480) = 443.401$, $p < 0.01$, with an R^2 change of 0.090, see Figure 6.6 for a summary of the contributing factors and the Appendix C for summary statistics of the regression model. Specifically, simulated teams' elevation in personal distress and perspective-taking positively impacted the propensity for selecting elegant ideas while the elevation in fantasy and empathic concern had a negative impact. Meanwhile, the diversity in fantasy and empathic concern positively impacted the propensity for selecting elegant ideas, while the diversity in personal distress and personal distress had a negative impact. The effect size of the overall model was considered medium.

The third hierarchical regression model investigated the role of team empathy elevation and diversity on the propensity for selecting **useful** ideas. The results from the third hierarchical regression model showed that team's propensity for selecting ideas rated high in drawing abilities, design context and problem, as well as the course instructor, significantly predicted simulated teams' propensity for selecting **useful ideas**, $R^2 = 0.163$, $F(4, 13480) = 654.098$, $p < 0.01$, which is considered a small effect. The addition of team empathy elevation and team empathy diversity to this model also led to a statistically significant model $F(12,13480) = 395.137$, $p < 0.01$, with an R^2 change of 0.097, see Figure 6.6 for a summary of the contributing factors and the Appendix C for summary statistics of the regression model. Specifically, simulated teams' elevation in personal distress and perspective-taking positively impacted the propensity for selecting useful ideas while the elevation in fantasy and empathic concern had a negative impact. Meanwhile, the diversity in fantasy and empathic concern positively impacted the propensity for selecting useful ideas, while the diversity in personal distress and personal distress had a negative impact. The effect size of the overall model was considered medium.

Finally, the fourth hierarchical regression model investigated the role of team empathy elevation and diversity on the propensity for selecting **unique** ideas. The results from the fourth hierarchical regression model showed that team's propensity for selecting ideas rated high in drawing abilities, design context and problem, as well as the course instructor, significantly predicted simulated teams' propensity for selecting **unique ideas**, $R^2 = 0.198$, $F(4, 13480) = 829.690$, $p < 0.01$, which is considered a small effect. The addition of team empathy elevation and team empathy diversity to this model also led to a statistically significant model $F(12,13480) = 519.387$, $p < 0.01$, with an R^2 change of 0.118, see Figure 6.6 for a summary of the contributing factors and the Appendix C for summary statistics of the regression model. Specifically, simulated teams' elevation in empathic concern positively impacted the propensity for selecting unique ideas while fantasy, perspective-taking, and personal distress had a negative impact. Meanwhile, the diversity in personal distress positively impacted the propensity for selecting unique ideas, while the diversity in perspective-taking and empathic concern had a negative impact; the diversity in fantasy had no significant impact.

6.6 Discussion

The main goal of this paper was to explore the role of team empathy in concept generation and selection. The main findings from this study indicated that the utility of the elevation and diversity of different types of empathy varied depending upon the specific design outcome (elegance, usefulness, uniqueness) and design stage (concept generation and selection). These results highlight the complicated nature of empathy in design and call against a one-size fits all view of empathy in design. The remainder of this section highlights the results with respect to the research questions.

6.6.1 The role of empathy in concept generation

The findings from concept generation corroborate with prior research that displays varying points of view on the role of empathy in concept generation [11, 12, 22]. For example, in terms of the number of ideas generated by design teams, teams' elevation in empathic concern and fantasy positively impacted the number of the ideas generated, while the elevation in personal distress and perspective-taking negatively impacted the number of ideas generated. Meanwhile, the diversity in fantasy had a positive impact on the number of ideas generated while the diversity in personal distress negatively impacted the number of generated ideas.

In terms of the overall creativity of the ideas generated, the findings from this research indicated that the elevation in all trait empathic tendencies positively impacted overall creative ideas. Meanwhile, the diversity in personal distress and perspective-taking positively impacted the general of overall creative ideas while the diversity in fantasy and empathic concern had a negative impact. In terms of elegance, the elevation in empathic concern positively impacted the generation of elegant ideas while the elevation in fantasy, perspective-taking, personal distress had a negative impact. Meanwhile, the diversity in fantasy, perspective-taking, personal distress had a positive impact on elegant idea generation while the diversity in empathic concern had a negative impact. In terms of useful idea generation, the elevation in empathic concern positively impacted the average usefulness of the ideas generated while fantasy, perspective-taking, and personal distress had a negative impact. Meanwhile, the diversity in personal distress positively impacted the usefulness of teams' ideas, while the diversity in empathic concern had a negative impact. Finally, in terms of unique idea generation, the elevation in fantasy, perspective-taking, and personal distress positively impacted the average uniqueness generated by teams. Meanwhile, the diversity in fantasy and perspective-taking positively impacted the uniqueness of teams' ideas, while the diversity in personal distress and empathic concern had the opposite effect.

Taken as a whole, the results highlight the complicated nature of the role of empathy in design and confirm prior research on the varying roles of empathy in the design process [11, 12, 22]. Specifically, the results highlighted that different components of trait empathy had both a positive and negative impact on the number of ideas generated as well as the creativity (overall creativity, usefulness, uniqueness, and elegance) of those ideas. Some of these results relate to findings in the literature that notes how being empathic may restrict the designer from coming up with creative innovations to the existing problem [81], commonly referred to as the empathy trap [21, 22]. Breithaupt [22] refers to this form of empathy as empathic vampirism, suggesting that the designer would end up designing for themselves if they over empathize [21].

6.6.2 The role of empathy in concept selection

The results from concept selection are similar in nature to the concept generation stage, whereby we find evidence that supports the notion that the elevation and diversity of different types of team empathic tendencies varied depending upon the specific design outcome (overall creativity, elegance, usefulness, uniqueness). These results confirm prior work that discussed that empathy could have positive [11, 12] and negative [55, 71, 81] impacts design. For instance, in terms of teams' propensity for selecting useful ideas, the elevation in personal distress and perspective-taking positively impacted the propensity for selecting useful ideas while the elevation in fantasy and empathic concern had a negative impact. Meanwhile, the diversity in fantasy and empathic concern positively impacted the propensity for selecting useful ideas, while the diversity in personal distress and perspective-taking had a negative impact.

In terms of teams' propensity for selecting overall creative ideas, the elevation in empathic concern positively impacted the propensity for selecting overall creative ideas while fantasy, perspective-taking, and personal distress had a negative impact. Meanwhile, the diversity in fantasy positively impacted the propensity for selecting overall creative ideas, while the diversity in personal distress and empathic concern had a negative impact. In terms of teams' propensity for selecting unique ideas, the elevation in empathic concern positively impacted the propensity for selecting unique ideas while fantasy, perspective-taking, and personal distress had a negative impact. Meanwhile, the diversity in personal distress positively impacted the propensity for selecting unique ideas, while the diversity in perspective-taking and empathic concern had a negative impact. Finally, in terms of teams' propensity for selecting elegant ideas, the elevation in personal distress and perspective-taking positively impacted the propensity for selecting elegant ideas while the elevation in fantasy and empathic concern had a negative impact. Meanwhile, the diversity in fantasy and empathic concern positively impacted the propensity for selecting elegant ideas, while the diversity in personal distress and personal distress had a negative impact.

This research adds to the existing body of knowledge by suggesting that while empathy may be useful throughout the design, the utility of specific types of empathy vary depending upon the design stage and design outcome. This is in line with prior work in psychology that suggests the importance of triggering interventions targeted towards specific components of empathy [192].

Taken as a whole, the findings from this chapter call for the importance of identifying which outcome (overall creativity, elegance, usefulness, uniqueness) is desired, and thus compose teams based on the empathic tendency (fantasy, personal distress, perspective-taking, and empathic concern) these outcomes are impacted by.

6.6.3 Implications for design education

Notably, there are some similarities and discrepancies between the results highlighted in Chapter 5 and those reported in the current chapter. Specifically, on an individual level, empathic concern tendencies positively predicted the general of more ideas while personal distress negatively impacted the generation of more ideas. These results were similar in nature on a team level where elevation in empathic concern positively impacted the number of the ideas generated, while the elevation and diversity in personal distress negatively impacted the number of ideas generated. However, there were also discrepancies. For instance, the elevation in all trait empathic tendencies positively impacted overall creative ideas, while these results were not significant for individual participants. Overall, these results highlight that the results from individuals can not necessarily be extrapolated to teams due to the non-summative effects from teamwork that might not be captured with the studies that solely report individual data [122].

Depending on the learning outcomes of the course and the nature of the design project, educators need to identify which design stage is more relevant and what design outcome is desired, and thus target interventions and compose teams based on that specific design stage (e.g., concept generation or concept selection). In first year design courses, both the concept generation and selection stages are critical and educators typically spend an equal amount of time on both of these stages [70, 123]. However, these stages are inherently different in terms of the educational outcomes and cognitive skillsets that are used in these stages. For example, Toh and Miller [6, 94] identified that the cognitive skills used in concept selection are very different from the skills used during concept generation. In the same line of research, Hay et al. [135] found that different design activities might require different working memory operators and reasoning processes based on the specific design goals [134]. In terms of the design outcomes, all of the four design outcomes (overall creativity, usefulness, uniqueness, and elegance) are ideally important since they constitute creative design outcomes – an essential component of design thinking in engineering design education [57, 76, 77]. However, on a team level, the team composition recommendations were found to be different between concept generation and concept selection. Thus, it would not be ideal or feasible to re-form teams between concept generation and selection. Therefore, educators might be required to select between those two design stages depending on the nature of the design project.

In addition to driving design outcomes, these results advance design science by identifying team empathic composition recommendations. Since empathy and its related concepts are important outcomes in cornerstone design courses [70], the insights from this dissertation could be used to add to that body of knowledge that could be delivered to engineering students through lectures and other empathy-building activities. This is in congruence with current insights in design education that stress the need to provide theoretical insights to design students as part of developing students' academic competence [198].

6.7 Conclusions and Future Work

The main goal of this paper was to explore the role of team empathy on concept generation and selection in an engineering design student project. Studying empathy in a team setting is of particular importance in this chapter due to the belief that a team of designers *could* have the ability to come up with more creative solutions than individual designers alone. Formalizing the role of team empathy in the design process provides clarity to *if*, *when*, or *how* empathy impacts creative design outcomes in the concept generation and selection stages of the design process. In order to achieve this goal, a computational simulation study examined the empathic composition of 13,482 nominal brainstorming teams composed of four members. The simulated teams were generated from a design repository of 806 ideas generated by 103 first-year engineering design students. The main findings from the study indicated that the utility of the elevation and diversity of different types of team empathy varied depending upon the specific design outcome (overall creativity, elegance, usefulness, uniqueness) and design stage (concept generation and selection). These results highlight the complicated nature of the role of empathy in design and confirm prior research on the varying roles of empathy in the design process.

However, there are several limitations that need to be identified that could lead to interesting avenues for future research. First, due to the nature of the simulation study, simulated team members were not aware of their team membership. Therefore, this study does not account for social effects (e.g., social loafing [60]), and the results should thus be interpreted conservatively. Second, while this work studied the relationship between empathy and the team's ability to generate and select elegant, useful, or unique ideas, future work should investigate other design outcomes, such as the quality of the final design. Finally, while prior research found that the ideation patterns of first-year and senior-level students differ [52], this work only studied first-year students. Thus, future research is warranted to extend those findings beyond first-year student design teams. Taken as a whole, this research is one of the first to study empathy on a team level. The findings from this research can organize team processes in engineering design in order to drive creative design outcomes.

CHAPTER 7

Composing empathic design teams: a simulation-based investigation on the role of personality traits and risk-taking attitudes on team empathy

This chapter is based on *preliminary* work accepted for publication in the proceedings of the Ninth International Design Computing and Cognition (DCC) conference. This work is multiple-authored by Mohammad Alsager Alzayed, Dr. Christopher McComb, and Dr. Scarlett Miller. Mohammad Alsager Alzayed is the lead author on the paper, and Dr. Scarlett Miller and Dr. Christopher McComb helped advise this work.

7.1 Abstract

While Chapter 5 (Paper II) and Chapter 6 (Paper III) highlighted the impact of empathy in engineering design, Chapter 7 presents a preliminary analysis of future work that starts to investigate the cognitive composition of empathic design teams. This is important since prior research has identified that individual differences may impact an individual's empathy. Two such individual differences that are critical in shaping the design outcomes of engineering designers and that have been found to influence empathy are personality traits and risk-taking attitudes. While this prior research provides a context for *why* individual differences may impact a designer's empathy, engineering design activities are typically deployed in teams, and thus a team-centered view of empathy is also needed.

As such, the goal of the preliminary study presented in this chapter was to investigate the role of the diversity in personality traits and risk-taking attitudes in impacting team empathy in engineering design. This was accomplished through a computational simulation of 13,482 teams

generated by a statistical bootstrapping technique drawing upon a data set from 103 first-year engineering students. The *preliminary* results from this chapter identify the importance of team diversity in personality (extraversion, neuroticism, and openness) and risk-taking attitudes (ethical, health/safety, and social) when composing highly empathic teams. Composing empathic teams is important since empathy could allow design teams to deeply understand the needs of diverse users and subsequently solve those users' problems.

7.2 Introduction

The ability to understand the feelings and circumstances of others [46], also known as empathy, has proven to be an effective driver of creative design outcomes [11] and thus is seen as a core constituent of engineering design [56]. While this prior work highlighted the importance of empathy in engineering design, research has also identified that individual differences may impact an individual's empathy [48, 199-203]. Two such individual differences that are critical in shaping the design outcomes of engineering designers and that have been found to influence empathy are personality traits [94, 199, 200, 203] and risk-taking attitudes [94, 201, 202]. For example, Eysenck et al. [203] found trait empathy to be positively correlated to the personality attribute neuroticism while Shu et al. [201] reported that individuals that take an empathic perspective were also found to be risk averse.

While this line of research provides some evidence on the role of personality and risk taking on an *individual* level, we do not know how they impact *team* empathy. This is problematic because teams are an essential component of engineering design [29], due to their ability to support problem solving [32] and improve the exploration of the solution space [33]. Studying empathy in a team setting is of particular importance in this study due to the belief that a team of designers *could* have the ability to come up with more creative solutions than individual designers alone [204]. As such, investigating the impact of the composition of teams on team empathy is warranted. The *diversity* of team attributes in terms of risk taking attitudes and personality attributes is of interest in the current study due to prior research that has identified the impact of diversity (e.g., racial [103], cognitive [187], cultural [205]) on empathic behavior. This also resonates with Stephen Covey's popular philosophy that states that "strength lies in differences, not similarities" [206].

Specifically, personality traits and risk-taking attitudes are the focus in the current study due to prior work that found that those two attributes are critical in shaping the design outcomes of engineering designers [94] and that have been found to influence an individual's empathy [199-203]. On an individual level, personality traits have been found to impact an individual's empathy [199, 200]. For some researchers such as Mitsopoulou and Giovazolias [207], trait empathy was considered a constituent of personality. For example, exploitativeness in the narcissism scale was negatively related to three different empathy scales [208]. Using the I6 impulsiveness questionnaire, Eysenck et al. [203] found trait empathy to be positively correlated to the personality attribute neuroticism.

Additionally, risk-taking attitudes, another facet of personality that is related to design outcomes in engineering design [94], were also found to be related to trait empathy. Specifically, individuals that take an empathic perspective were found to be risk averse [201]. This phenomenon has also been confirmed in a behavioral study by Ogawa et al. [202] that found that empathic concern, as measured by Davis's Interpersonal Reactivity Index (IRI) [48], was related to risk-averseness. While prior work highlights the role of those individual characteristics (e.g., personality, risk-taking, etc.) as predictors of empathy, that previous line of research is not based on an engineering sample, and has not been studied on a team level.

On a team level, diversity in personality attributes been used as a factor to form teams in engineering design for the purposes of driving innovation [95], productivity [96, 97], and leadership [98, 99], but n*ot* empathy. By measuring team personality elevation and team personality diversity [36], Neuman, Wagner, and Christiansen concluded that teams with diverse personalities performed better on tasks on an unmanned aerial vehicle control system [95]. On the same line of research, Sook Kim et al. [100] found that diversity, in terms of team members' creative modes, positively impacted team cohesiveness. In the context of empathy, prior research has reported that diversity could be a mediator to empathic behavior in social settings [103]. In engineering design, Wong, Sorris, and Siddique [104] claim that empathy is a precursor to an inclusive and diverse environment in engineering design. While that body of research suggests a linkage between diversity and empathy, it has not empirically studied the relationship between team empathy and personality diversity, or diversity in risk-taking attitudes.

Formalizing the role of team diversity in personality traits and risk-taking on team empathy could provide the design community with a better understanding of how to formulate empathic design teams. As such, the objective of this paper was to identify the role of team personality and risk-taking attributes on team trait empathy. We turn our attention to studying trait empathy, a dispositional quality that allows for the understanding of the emotions, circumstances, and needs of others [46], as opposed to designers' perceived empathy, due to prior research that reported that one's empathic tendencies could be most accurately identified with their trait empathy [48]. Specifically, this paper sought to study the average (commonly referred to as elevation [36]) and standard deviation (commonly referred to as diversity ([36]) of team's trait empathy, due to recent research that found that both empathy elevation and diversity impacted creative design outcomes in the design process [194]. This research is one of the first to study trait empathy on a team level and provide some of the first insights on the empathic composition of teams in engineering design.

7.3 Research Objectives

Based on this prior work, the objective of this paper was to identify the role of team personality and risk-taking attributes on team trait empathy. This paper sought to study the average (commonly referred to as elevation [36]) and standard deviation (commonly referred to as diversity [36]) of team trait empathy. The factors studied in this investigation are summarized in Figure 7.1. Specifically, the following hypotheses were devised:

- Diversity in personality traits could be used to predict higher levels of trait empathy elevation since prior research has reported that diversity could be a mediator to empathic behavior [103, 187, 205].
- Diversity in risk-taking attitudes could be used to predict higher levels of trait empathy elevation since prior research has reported that diversity could be a mediator to empathic behavior [103, 187, 205].

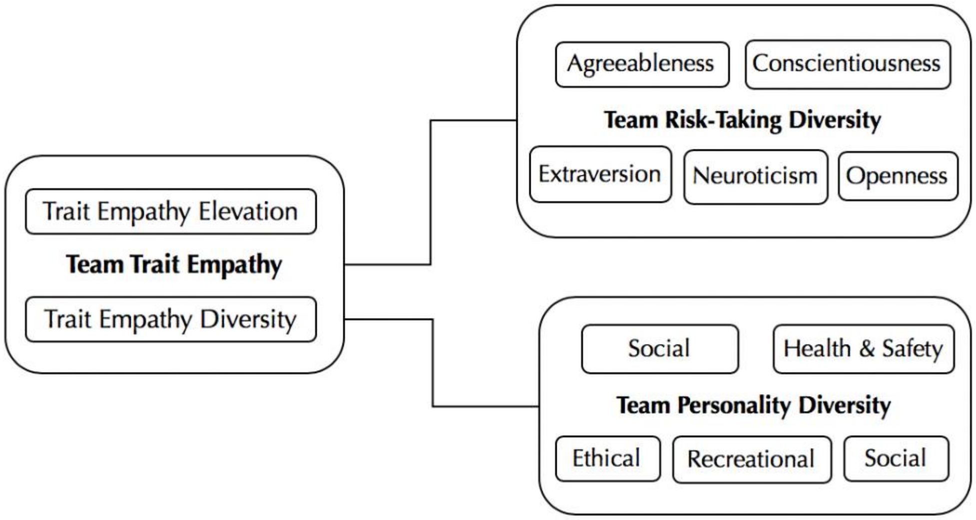

Figure 7.1 Summary of the factors studied in Chapter 7

7.4 Methodology

The data set for this study was derived from a study conducted with 103 first-year engineering students (73 men and 30 women) from four sections of a cornerstone engineering design course that participated in an 8-week design project [163, 188]. The design project focused on the following engineering challenges: (1) lack of safe water, sanitation, and hygiene services, (2) access to vaccinations, (3) indoor and ambient air pollution, and (4) road traffic injuries [163, 188]. While design teams were tasked with the same design problems, two of the four course sections focused on designing for the *developing* world, while the remaining sections focused on designing for the *developed* world, see [209] for the problem statements. Chapter 3 provides a detailed explanation of the data collection procedure.

Prior to the start of the study, participants completed a 28-item survey that measured their trait empathy. They were also asked to complete a 30-item survey assessing their risk-taking attitudes and a 120-item personality test (see data collection instruments for detailed description) as homework assignments in week 5. The data set was used to run a computational simulation of

13,482 nominal groups [111-113]. Nominal groups are defined as individuals that work independently and pool their solutions together near task completion [111-113] and have been widely used in simulation-based research [106-108] since this grouping technique has been found to foster input from all team members [111, 112, 114], as well as boost team productivity [114]. Further details on the simulation procedure can be found in section 6.4. Specifically, the aim of the simulation was to study the role of personality traits and risk-taking attributes in impacting team empathy.

7.4.1 Data Collection and Instruments

This section summarizes the metrics used to explore the factors critical to achieving the research objectives.

7.4.1.1 Trait Empathy

Participants' trait empathy was measured using the IRI [48], a 28-item survey answered on a 5-point Likert scale ranging from "does not describe me well" to "describes me very well." Further details on the IRI scoring methodology can be found in section 3.3 of the dissertation.

To obtain a trait empathy score for each of the 103 participants, the IRI scores on empathic concern, fantasy, and perspective-taking were averaged for each participant [48]. Personal distress was not included in the analysis since it has been found to be negatively related to the other three IRI subscales [48], and hence adding personal distress with the other three IRI subscales is not advised [133].

Second, to obtain a trait empathy score for each of the 13,482 simulated teams, team empathy elevation, and team empathy diversity were considered. Team empathy elevation takes the average across all team members' trait empathy scores, while team empathy diversity takes the standard deviation in team members' trait empathy scores [36].

7.4.1.2 Personality Traits

Personality traits were measured using the short Five Factor Model online questionnaire [141], a short form of the International Personality Item Pool Representation of the NEO Personality Inventory-Revised [210], see section 3.3 for details. To obtain personality scores for each simulated team, team personality diversity [36] was considered, i.e., the standard deviation for each of the personality traits.

7.4.1.3 Risk-taking Attitudes

Risk taking attitudes were measured using a 30-item shortened version of the psychometric domain-specific risk-taking scale [142], see section 3.3 for details. To obtain risk-taking scores for each simulated team, team risk-taking diversity was considered for each of the five risk-taking subscales.

7.5 Results and Discussion

The main goal of the current study was to investigate the role of personality traits and risk-taking attitudes in impacting team empathy in engineering design. We hypothesized that diversity in personality traits could be used to predict higher levels of trait empathy elevation since prior research has reported that diversity could be a mediator to empathic behavior [103, 187]. Similarly, it was hypothesized that the diversity in risk-taking attitudes could be used to predict higher levels of trait empathy elevation [103, 187]. In order to answer our research questions, statistical analyses were computed using SPSS 25.0, and a significance level of 0.05 was used in all analyses. In addition, effect sizes were classified according to Cohen [186]. The remainder of this section outlines the results with respect to our research objectives.

In order to understand the role of personality traits and risk-taking attitudes on team trait empathy, two linear regression models were computed to predict simulated teams' (1) empathy elevation and (2) empathy diversity from the diversity of the personality traits (openness, extraversion, neuroticism, agreeableness, and conscientiousness), and the diversity of the risk-taking attitudes (social, ethical, health/safety, recreational and financial).

Prior to the analysis, statistical assumptions were checked. The results showed the linearity of the independent variables as assessed by partial regression plots and a plot of studentized residuals against the predicted values. By visual inspection of a plot of studentized residuals, the assumption of homoscedasticity was met. There was no multicollinearity in the independent variables, as assessed by tolerance values greater than 0.1 [189]. As assessed by the studentized deleted residuals greater than ±3 standard deviations, there were 25 and 14 outliers for the first and second regression models, respectively. The outliers were found to have no significant impact on the significance of the results, and therefore, the full analysis is presented here. Additionally, there were no leverage values greater than 0.2 [190], and no values for Cook's distance above 1 [191]. Finally, normality was confirmed by visually inspecting the histograms and Q-Q plots. Based on these results, the analysis proceeded as planned.

The results of the first regression model showed that the diversity in personality attributes and risk-taking attitudes significantly predicted team empathy elevation, F (10,13465) = 580.563, p = 0.008, R^2 = 0.301, a medium effect size, see Figure 7.2 for a summary of the contributing predictors. Specifically, the diversity in team extraversion, neuroticism, and openness as well as diversity in ethical, health/safety, and social risk-taking promoted team empathy elevation while the remaining personality traits and risk-taking attitudes negatively predicted team empathy elevation.

While the first regression model investigated the role of personality traits and risk-taking attributes on team empathy elevation, the second regression model investigated the impact of those factors on team empathy diversity. The results from the second regression model showed that team empathy diversity was significantly predicted from the diversity in personality traits and risk-taking attributes, F (10,13465) = 374.869, $p < 0.001$, R^2 = 0.218, a medium effect size. Specifically, the diversity in team openness and agreeableness in addition to teams' ethical, financial, health/safety, and recreational risk-taking promoted team empathy diversity while the remaining personality traits and risk-taking attitudes negatively predicted team empathy diversity, see Figure 7.2 for a summary of the contributing predictors.

These findings partially support our first hypothesis that the diversity in personality traits were related to team empathy [103, 187]. However, it pointed out that the diversity in some personality attributes negatively impact the empathy elevation and diversity in teams. Specifically, if highly empathic teams are desired, our results call for the importance of focusing on diversity in team extraversion, neuroticism, and openness. Meanwhile, if empathy diverse teams are desired, our results call for the importance of focusing on diversity in the openness and agreeableness personality traits.

Similarly, these findings partially support our second hypothesis that the diversity in risk-taking attributes was related to team empathy [103, 187]. Specifically, if highly empathic teams are desired, our results call for the importance of focusing on diversity in team ethical, health/safety, and social risk-taking. Meanwhile, if empathy diverse teams are desired, our results call for the importance of focusing diversity on ethical, financial, health/safety, and recreational risk-taking attitudes, but not social risk-taking.

When composing highly empathic teams, our results point to the composition of teams that are diverse in extraversion, openness, and neuroticism in addition to being diverse in ethical, health/safety, and social risk-taking. Meanwhile, if empathic diverse teams are sought, our results point to the composition of teams that are diverse in the openness and agreeableness personality traits as well as ethical, financial, health/safety, and recreational risk-taking attributes. However, these results call for future research that could validate these findings with a large sample of design teams in a human-subjects study. Taken as a whole, the results from this research can be used to guide empathic team formation. However, it warrants future research that would assess the role of other individual differences (e.g., gender [48]) with relation to team empathy.

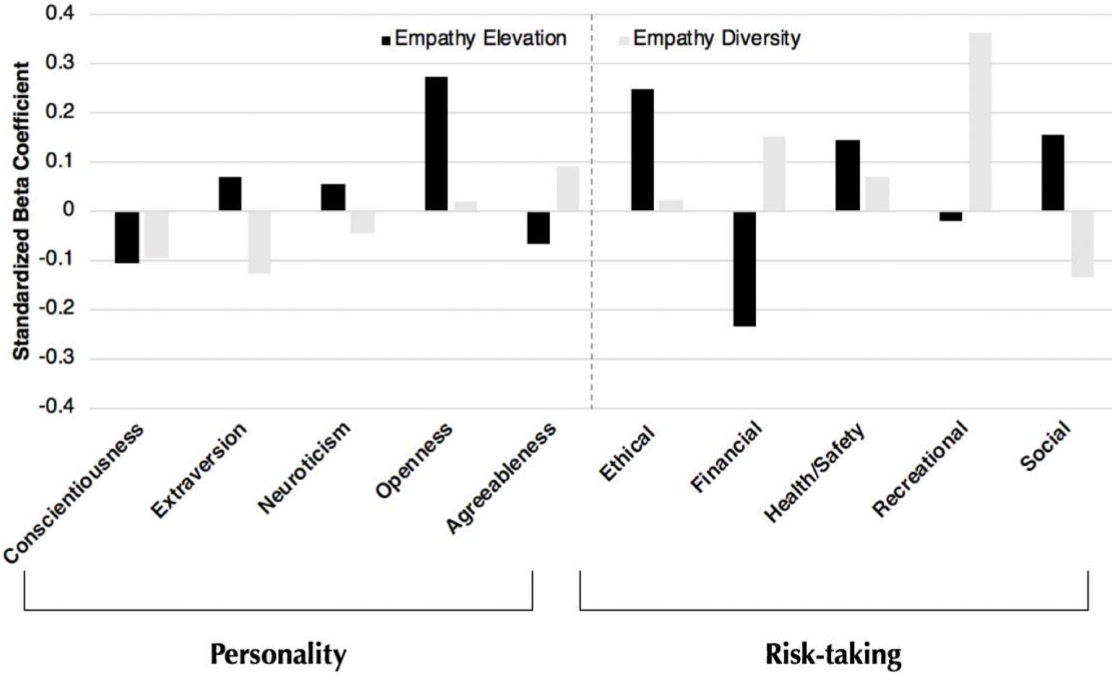

Figure 7.2 Standardized beta coefficients of the statistically significant predictors from the two linear regression models displaying the relationship between the diversity of simulated teams' personality traits and risk-taking attributes and (1) team trait empathy elevation & (2) team trait empathy diversity

7.6 Conclusion, Limitations, and Future Work

The main goal of the current study was to investigate the role of personality traits and risk-taking attitudes in impacting team empathy in engineering design. This was accomplished through a computational simulation of 13,482 teams of noninteracting individuals generated by a statistical bootstrapping technique drawing upon a data set from 103 first-year engineering design students. Taken as a whole, the results from this research corroborate previous research on *individuals* that found that personality traits and risk-taking attitudes predicted an individual's empathy [199-203]. Specifically, the main findings from this exploratory study call for the importance of focusing diversity in team extraversion, openness, and neuroticism in addition to the diversity in teams' ethical, health/safety, and social risk-taking when composing highly empathic teams. Meanwhile, if empathy diverse teams are desired, the results call for the importance of focusing diversity in the openness and agreeableness personality traits as well as ethical, financial, health/safety, and recreational risk-taking.

However, there are several limitations that lead to exciting avenues for future research. First, while this study assessed the role of personality traits and risk-taking attitudes on team empathy, future research should investigate other individual differences, such as the gender diversity prevalent in a team. Second, simulated team members were not aware of their team membership due to the nature of the simulation study. Thus, this study does not account for social effects (e.g., social loafing [114]) and the roles of team members [211-214]. Thus, future research is warranted to situate these results in a human-subjects study. Additionally, this study presented an aggregated measure of trait empathy that takes the average of three (perspective-taking, fantasy, empathic concern) of the four IRI empathic tendencies. Thus, future research is needed to assess the role of individual differences in relation to each of the four IRI empathic tendencies. Finally, while this study explored the role of personality traits and risk-taking attitudes of first-year engineering students, future research is warranted to explore these relationships across other populations. Taken as a whole, this research is one of the first to study empathy at a team level.

CHAPTER **8**

CONCLUSIONS AND CONTRIBUTIONS

This dissertation aimed at developing a systematic and empirically-grounded understanding of the factors that lead to the building or waning of empathy and its subsequent impact on creative design outcomes. Specifically, Paper I explored the development of students' empathy development and the underlying impact of the design and educational context on that development through the following means: (1) measurement of students' trait empathy and empathic self-efficacy throughout the design process, (2) analysis of student reflection essays, and (3) interviews with course instructors. While Paper I explored the development of students' empathy, Paper II investigated the relationship between student empathy and creative design outcomes in the concept generation and selection stages of the design process. Finally, Paper III studied the impact of the empathic composition of teams (elevation and diversity of team empathy) on creative design outcomes. The following sections of this chapter synthesize the findings of the three papers in this dissertation and point out future research directions.

8.1 The transitive nature of empathy in engineering design education

The first main contribution of this dissertation was the identification of the transitive nature of empathy in engineering education. In Paper I (Chapter 4), the results indicated that students' empathic concern and personal distress decreased across the design stages. The results from this study highlighted that students' trait empathy can change in a short period of time. However, the findings urge design education researchers to not rely *solely on* students' perceptions of their empathy when devising or assessing empathic activities in the engineering classroom, since the results from this dissertation found that students' perceptions of their empathy development did not align with the empirical results, potentially due to participants' attributional or social desirability biases. While this dissertation did not involve empathy-invoking interventions, the results call for the importance of devising interventions that invoke the specific empathic tendencies that promote design outcomes based on the findings from Chapter 5 (Paper II) and Chapter 6 (Paper III).

8.2 The impact of the design and educational context on empathy development

The second main contribution of this dissertation was the identification of the role of the context of the design problem and the course instructor in impacting empathy development in engineering design education. The results from this research indicated that the design context (developing versus developed world) did not impact students' empathy development. Meanwhile, the educational context was found to have an impact on empathy development as interviews with the course instructors identified several constraints in the applications of empathy building-activities including the lack of accessibility to the end-user. This would be particularly the case for students working on developing world projects where students might be additionally challenged to understand the culture and context of an end user who is often very different from themselves [65-67]. Additionally, instructors identified that the later design stages (concept generation and selection) involved less deliberate empathy-invoking activities compared to the earlier design stages. Taken as a whole, the findings from Chapter 4 call for the need for further empirical investigations that could assess the impact of pedagogical activities that involve an interaction with the end-user on students' trait empathy development; these activities include simulating user scenarios [13, 20] and conducting interviews with the end-users [156].

8.3 The relationship between trait empathy and creative design outcomes

The third contribution of this dissertation was deepening the understanding of the role of trait empathy on creative idea generation and selection. Specifically, the main findings from Chapter 5

(Paper II) identified that empathic concern tendencies positively impacted the generation of more ideas, while personal distress tendencies negatively impacted the generation of more ideas. During concept selection, perspective-taking tendencies positively impacted participants' propensity for selecting elegant ideas. The insights from this dissertation suggest that affective empathic tendencies (empathic concern and personal distress) were prevalent during concept generation while cognitive empathic tendencies (perspective-taking) were more prevalent during concept selection. The results from Chapter 5 suggest that while empathy may be useful throughout the design, the utility of specific types of empathy vary depending upon the design stage. Since the design community has become invested in devising empathy-invoking interventions [13, 20], the results from this research call for the need to prepare *specific* interventions that trigger certain types of empathic tendencies. This is in line with prior work in psychology that suggests the importance of triggering interventions targeted towards specific components of empathy [192]. Specifically, these findings indicated that interventions geared at empathic concern tendencies are favorable during concept generation while the design community should refrain from evoking personal distress tendencies during concept generation. Meanwhile, during concept selection, the findings from this dissertation suggest the value of triggering perspective-taking tendencies to allow designers to select elegant ideas.

8.4 The impact of the empathic composition of design teams on creative design outcomes

Finally, Chapter 6 presented the final contribution of this dissertation in the investigation of the empathic composition of design teams on creative design outcomes. The main findings from Chapter 6 of the dissertation highlighted that the utility of the elevation and diversity of different types of team empathy varied depending upon the specific design outcome (overall creativity, elegance, usefulness, uniqueness) and design stage (concept generation and selection). For instance, during concept selection, the diversity in fantasy and empathic concern tendencies prevalent in a team positively impacted the propensity for selecting useful ideas, while the diversity in personal distress and perspective-taking had a negative impact. However, there were discrepancies between the results from *individual* participants (Chapter 5) and those from teams (Chapter 6). This insight indicated that the results from individuals can not necessarily be extrapolated to teams due to the non-summative effects from teamwork that might not be captured with the studies that solely report data on individuals [122].

In addition to driving design outcomes, these results advance design science by identifying team empathic composition recommendations. Since empathy and its related concepts are important outcomes in cornerstone design courses [70], the insights from this dissertation could be used to add to that body of knowledge that could be delivered to engineering students through lectures and other empathy-building activities. This is in congruence with current insights in design education that stress the need to provide theoretical insights to design students as part of developing students' academic competence [198]. Overall, the findings from this dissertation highlight the complicated nature of the role of empathy in design and call against a one-size fits all view of empathy in design. Taken as a whole, the findings from this dissertation encourage engineering educators to identify which empathy tendency is desired and thus compose teams and design interventions based on the results presented in the chapter.

8.5 Limitations and Future Direction

While this dissertation investigated the role of empathy in the design process and explored factors that could play a role in developing students' empathy, there are several limitations that can lead to potentially impactful avenues for future research. First, while the results presented in this dissertation depict the absence of change in students' empathy across a design project, future work is needed to extend the results over both shorter (e.g., design tasks) and longer (e.g., across an entire semester) periods of time. Additionally, while this study empirically assessed students' trait empathy and empathic self-efficacy development, it did not involve empathy-evoking interventions, which future research should assess to identify the more successful in-class activities, in terms of empathy development. For example, technological tools could be used in the engineering classroom to simulate empathic design experiences that could allow student designers to be immersed in the lives of the end-user. However, future research is warranted to empirically assess whether such interventions impact students' cognitive and affective empathic tendencies.

Since there is no validated instrument to assess the cognitive and affective [47] components of empathy specifically in a design context, this study utilized Davis' IRI to assess empathy – an instrument that is originally contextualized in psychology rather than engineering design. Thus, due to the need to devise and assess pedagogical interventions geared at empathy development, this study calls researchers in engineering design to devise and validate a psychometric instrument that could assess the cognitive and affective components of empathy in a design context. Additionally, while the course instructor interviews provided insights into the potential factors that constricted students from developing empathy, member-checking [215] was not conducted on the analysis of the interviews. Thus, to provide further rigor and validity to the findings from the course instructor interviews, future iterations of this research should conduct member-checking on the interview findings, where the results are returned to participants to confirm the accuracy and resonance of the interpretations of the results based on participants' experiences [215]. To provide further rigor and validity to the findings from the course instructor interviews, future iterations of this research should conduct member-checking on the interview findings, where the results are returned to participants to confirm the accuracy and resonance of the interpretations of the results with participants' experiences [215]. Moreover, while this dissertation studied the relationship between empathy and the team's ability to generate and select elegant, useful, or unique ideas, future work should investigate other design outcomes, such as the quality of the final design. While this dissertation investigated the relationship between trait empathy and creative design outcomes, it calls for future research that could capture students' motivation throughout these tasks as motivation could be a mediator factor to students' empathy [55, 193] and creativity [86] by impacting their attitudinal stance toward the design task. Additionally, future research is warranted to identify the impact of empathy on other educational outcomes in design education such as problem solving [216] and motivation [217], since the main goal of most design courses is learning [216], and not merely design outcomes. Finally, while this research explored the utility of empathy in humanitarian engineering problems, future research is needed to extend these results with other engineering design tasks.

In terms of the simulation study presented in Chapter 6, due to the nature of the simulation study, simulated team members were not aware of their team membership. Therefore, the simulation does not account for social effects (e.g., social loafing [114]), and the roles of team members [211-214]. Thus, future research is warranted to situate these results in a human-subjects study. Additionally, while this dissertation investigated the impact of the diversity of personality traits and risk-taking attitudes on team empathy, future research should investigate the impact of psychological diversity on other educational outcomes such as problem solving and team cohesiveness. Finally, while prior research found that the ideation patterns of first-year and senior-level students differ [106], this dissertation only studied first-year students. Thus, future research is warranted to compare the results presented in this dissertation across different educational levels to expand the applicability and the implications of findings.

8.6 Conclusion

This dissertation aimed at developing a systematic and empirically-grounded understanding of the factors that lead to the building or waning of empathy and its subsequent impact on creative design outcomes. The results from this dissertation urge design education researchers to not rely *solely on* students' perceptions of their empathy when devising or assessing empathic activities in the engineering classroom, since the results from this dissertation found that students' perceptions of their empathy development did not align with the empirical results. A more detailed analysis of students' activities during concept generation and selection revealed that empathy might be useful in different ways during different design stages depending on the specific design outcome. Finally, this dissertation provides recommendations for composing teams in engineering design education. Taken as a whole, this dissertation presents one of the first and most extensive empirical investigations aimed at formalizing the role of empathy in engineering design education. The pursuit of such a formalization is critical, given the need for those graduating engineers to engage with a broad range of stakeholders. Without understanding *when* or *how* to prepare those graduating engineers to be empathic in engineering education, the graduating engineering workforce could fail to understand the needs of diverse users and subsequently fail in solving those users' problems.

APPENDIX A – INTERVIEW SCRIPT

Introduction

- [Introduction of interviewer]
- [Discussion of the IRB Procedure and consent]
- [Introduce the goal of the interview] The main goal of this interview is to understand how the different in-class activities impacted students' empathy development during the first 8-week project in EDSGN 100
- [Ask for consent for recording the conversation] Do you mind if we record the conversation, for annotation purposes? Any personal references will be omitted.

Interview Questions

1) Do you think empathy was an important aspect of your design project this semester? Why or why not?

   We define empathy as "a social and emotional skill that helps students feel and understand the emotions, circumstances, intentions, thoughts, and needs of others such that we can offer sensitive, perceptive, and appropriate communication and support."

2) Can you give me an example about a team or a moment in a team where the team was particularly empathic in the design process?

3) Can you tell me about a team or a moment in a team where the team was not very empathic in the design process?

4) In what way do you think your students developed empathy in your course? Please discuss with reference to the following design stages: (1) problem formulation, (2) concept generation, (3) concept selection, and (4) prototyping and detailed design?
   a. What factors do you think restricted the students from developing empathy across those design stages?

5) Were there any particular activities you think were particularly useful for helping students develop empathy in your project? Why?

6) Were there any particular activities you think were NOT particularly useful for helping students develop empathy in your project? Why?

ENDING STATEMENT

APPENDIX B – CODEBOOK FROM CHAPTER 4

Empathic Tendency	Themes	Description
Perspective-Taking	Idea Generation	The participant discusses idea generation with reference to this empathic tendency
	Teamwork	The participant discusses teamwork with reference to this empathic tendency
	Concept Selection	The participant discusses concept selection with reference to this empathic tendency
	Understanding of culture	The participant discusses cultural awareness/understanding with reference to this empathic tendency
	Motivation	The participant discusses their motivation on the project/course with reference to this empathic tendency
	User Needs Assessment	The participant discusses the assessment/generation of users' needs with reference to this empathic tendency
	Other	The participant is discussing this empathic tendency but it is not clear which of the above themes it is referring to
Empathic Concern	Idea Generation	The participant discusses the idea generation stage of the

Empathic Tendency	Themes	Description
		design process with reference to this empathic tendency
	User Needs Assessment	The participant discusses the assessment/generation of users' needs with reference to this empathic tendency
	Motivation	The participant discusses their motivation on the project/course with reference to this empathic tendency
	Concept Selection	The participant discusses the concept selection stage of the design process with reference to this empathic tendency
	Other	The participant is discussing this empathic tendency but it is not clear which of the above themes it is referring to
Personal Distress	No theme	The participant discusses this empathic tendency
Fantasy	Persona	The participant deeply discuss how they were transposed imaginatively into the persona's life
Not Explicitly Stated or General Empathy	Feelings of empathy increase	The participant is discussing that their empathy is increasing
	Feelings of empathy decrease	The participant is discussing that their empathy is decreasing
	Feelings of no change in empathy	The participant is feeling that their empathy did not change
	Motivation	The participant discusses their motivation on the project/course with reference to empathy but without a particular reference to any of the four empathic tendencies

Empathic Tendency	Themes	Description
	Teamwork	The participant discusses teamwork with reference to empathy but without a particular reference to any of the four empathic tendencies
	Concept Selection	The participant discusses the concept selection process with reference to empathy but without a particular reference to any of the four empathic tendencies
	Idea Generation	The participant discusses the idea generation process with reference to empathy but without a particular reference to any of the four empathic tendencies
	Prototyping & Detailed Design	The participant discusses any instances of prototyping or detailed design with reference to empathy but without a particular reference to any of the four empathic tendencies
	User Needs Assessment	The participant discusses the assessment/generation of users' needs with reference to this empathic tendency
	Understanding of culture	The participant discusses cultural awareness/understanding with reference to this empathic tendency

APPENDIX C – REGRESSION TABLES FROM CHAPTER 5

Table 1. Summary statistics of the regression model on the relationship between the number of ideas generated by simulated teams and team trait empathy elevation and diversity

Step	Factor		*B*	*SE*	*β*	*p*
1	Context		-3.276	.372	-.209	<0.01
	Problem		-.976	.111	-.099	<0.01
	Instructor		8.701	.302	.771	<0.01
2	Context		-.532	.387	-.034	0.169
	Problem		-.917	.108	-.093	<0.01
	Instructor		7.275	.294	.645	<0.01
	Elevation	Fantasy	.385	.031	.111	<0.01
		Personal Distress	.484	.023	.198	<0.01
		Perspective-Taking	-.488	.025	-.162	<0.01
		Empathic Concern	-.627	.032	-.203	<0.01
	Diversity	Fantasy	-.020	.040	-.004	0.624
		Personal Distress	.506	.030	.125	<0.01
		Perspective-Taking	-.837	.030	-.224	0.680
		Empathic Concern	-.014	.039	-.003	0.729

Note: B represents the unstandardized coefficient; SE represents the standard error associated with that coefficient; β is the standardized coefficient; p is the significance value associated with each factor

Table 2. Summary statistics of the regression model on the relationship between the average usefulness and uniqueness of simulated teams' ideas and team trait empathy elevation and diversity

Model	Step	Factor		*B*	*SE*	*β*	*p*
Average usefulness of ideas generated	1	Average Drawing Abilities		.245	.006	.350	<0.01
		Context		.185	.009	.490	<0.01
		Problem		-.018	.003	-.074	<0.01
		Instructor		-.171	.007	-.630	<0.01
	2	Average Drawing Abilities		.221	.006	.315	<0.01
		Context		.248	.010	.654	<0.01
		Problem		-.010	.003	-.041	<0.01
		Instructor		-.206	.007	-.756	<0.01
		Elevation	Fantasy	-.003	.001	-.048	<0.01
			Personal Distress	-.019	.001	-.259	<0.01
			Perspective-Taking	-.006	.001	-.081	<0.01
			Empathic Concern	.012	.001	.142	<0.01
		Diversity	Fantasy	-.001	.001	-.012	0.110
			Personal Distress	.007	.001	.078	<0.01
			Perspective-Taking	.000	.001	.003	0.680
			Empathic Concern	-.008	.001	-.071	<0.01
Average uniqueness of ideas generated	1	Average Drawing Abilities		.292	.010	.187	<0.01
		Context		1.519	.016	1.804	<0.01
		Problem		.272	.005	.514	<0.01
		Instructor		-.825	.013	-1.363	<0.01
	2	Average Drawing Abilities		.326	.011	.246	<0.01
		Context		1.414	.018	1.682	<0.01
		Problem		.261	.005	.486	<0.01
		Instructor		-.808	.013	-1.326	<0.01
		Elevation	Fantasy	.003	.001	.023	.314
			Personal Distress	.006	.001	.038	<0.01
			Perspective-Taking	.027	.001	.165	<0.01
			Empathic Concern	.002	.001	.009	<0.01
		Diversity	Fantasy	.012	.001	.056	<0.01
			Personal Distress	-.017	.001	-.087	<0.01
			Perspective-Taking	.009	.002	.032	<0.01
			Empathic Concern	-.006	.002	-.025	<0.01

Table 3. Summary statistics of the regression model on the relationship between the average overall creativity and elegance of simulated teams' ideas and team trait empathy elevation and diversity

Model	Step	Factor		*B*	*SE*	*β*	*p*
Average overall creativity of ideas generated	1	Average Drawing Abilities		.361	.009	.319	<0.01
		Context		.868	.014	1.422	<0.01
		Problem		.138	.004	.358	<0.01
		Instructor		-.446	.011	-1.016	<0.01
	2	Average Drawing Abilities		.360	.009	.319	<0.01
		Context		.799	.015	1.310	<0.01
		Problem		.129	.004	.334	<0.01
		Instructor		-.457	.011	-1.040	<0.01
		Elevation	Fantasy	.006	.001	.061	<0.01
			Personal Distress	.002	.001	.019	0.025
			Perspective-Taking	.011	.001	.089	<0.01
			Empathic Concern	.009	.001	.068	<0.01
		Diversity	Fantasy	-.001	.001	-.005	0.526
			Personal Distress	.007	.001	.048	<0.01
			Perspective-Taking	.019	.002	.093	<0.01
			Empathic Concern	-.001	.002	-.003	0.706
Average elegance of ideas generated	1	Average Drawing Abilities		.412	.009	.422	<0.01
		Context		-.087	.014	-.165	<0.01
		Problem		.025	.004	.075	<0.01
		Instructor		.103	.011	.271	<0.01
	2	Average Drawing Abilities		.360	.009	.369	<0.01
		Context		-.021	.015	-.040	.155
		Problem		.039	.004	.119	<0.01
		Instructor		.059	.011	.155	<0.01
		Elevation	Fantasy	-.009	.001	-.105	<0.01
			Personal Distress	-.014	.001	-.137	<0.01
			Perspective-Taking	-.007	.001	-.063	<0.01
			Empathic Concern	.012	.001	.106	<0.01
		Diversity	Fantasy	.000	.001	.001	0.897
			Personal Distress	.017	.001	.137	<0.01
			Perspective-Taking	.007	.001	.043	<0.01
			Empathic Concern	.000	.002	-.003	0.781

Table 4. Summary statistics of the regression model on the relationship between the propensity for selecting useful and unique ideas and team trait empathy elevation and diversity

Model	Step	Factor		*B*	*SE*	*β*	*p*
Propensity for selecting useful ideas	1	Average Drawing Abilities		.447	.010	.412	<0.01
		Context		-.022	.003	-.209	<0.01
		Problem		.005	.001	.077	<0.01
		Instructor		-.001	.002	-.010	0.719
	2	Average Drawing Abilities		.458	.009	.422	<0.01
		Context		-.038	.003	-.361	<0.01
		Problem		.006	.001	.098	<0.01
		Instructor		.010	.002	.131	<0.01
		Elevation	Fantasy	.004	.000	.192	<0.01
			Personal Distress	.002	.000	.123	<0.01
			Perspective-Taking	-.004	.000	-.174	<0.01
			Empathic Concern	.001	.000	.056	<0.01
		Diversity	Fantasy	-.003	.000	-.129	0.110
			Personal Distress	-.003	.000	-.088	<0.01
			Perspective-Taking	.003	.000	.087	0.680
			Empathic Concern	.004	.000	.192	<0.01
Propensity for selecting unique ideas	1	Average Drawing Abilities		.423	.015	.236	<0.01
		Context		-.027	.004	-.156	<0.01
		Problem		.031	.001	.283	<0.01
		Instructor		.041	.004	.333	<0.01
	2	Average Drawing Abilities		.498	.015	.279	<0.01
		Context		-.014	.005	-.081	<0.01
		Problem		.033	.001	.302	<0.01
		Instructor		.027	.004	.217	<0.01
		Elevation	Fantasy	-.003	.000	-.133	<0.01
			Personal Distress	-.005	.000	-.160	<0.01
			Perspective-Taking	-.001	.000	-.024	0.026
			Empathic Concern	.014	.000	.385	<0.01
		Diversity	Fantasy	.000	.000	-.013	0.103
			Personal Distress	.003	.000	.075	<0.01
			Perspective-Taking	-.006	.000	-.120	<0.01
			Empathic Concern	-.007	.000	-.133	<0.01

Table 5. Summary statistics of the regression model on the relationship between the propensity for selecting overall creative and elegant ideas and team trait empathy elevation and diversity

Model	Step	Factor		*B*	*SE*	*β*	*p*
Propensity for selecting overall creative ideas	1	Average Drawing Abilities		.378	.013	.256	<0.01
		Context		.084	.004	.587	<0.01
		Problem		.029	.001	.323	<0.01
		Instructor		-.047	.003	-.459	<0.01
	2	Average Drawing Abilities		.405	.013	.274	<0.01
		Context		.100	.004	.694	<0.01
		Problem		.030	.001	.332	<0.01
		Instructor		-.057	.003	-.550	<0.01
		Elevation	Fantasy	-.001	.000	-.027	0.016
			Personal Distress	-.002	.000	-.065	<0.01
			Perspective-Taking	-.003	.000	-.104	<0.01
			Empathic Concern	.006	.000	.184	<0.01
		Diversity	Fantasy	.001	.000	.043	<0.01
			Personal Distress	-.002	.000	-.067	<0.01
			Perspective-Taking	.000	.000	-.012	0.177
			Empathic Concern	-.003	.000	-.080	<0.01
Propensity for selecting elegant ideas	1	Average Drawing Abilities		.465	.013	.308	<0.01
		Context		.098	.004	.671	<0.01
		Problem		.007	.001	.079	<0.01
		Instructor		-.064	.003	-.606	<0.01
	2	Average Drawing Abilities		.433	.013	.286	<0.01
		Context		.080	.004	.544	<0.01
		Problem		.007	.001	.079	<0.01
		Instructor		-.056	.003	-.530	<0.01
		Elevation	Fantasy	-.001	.000	-.029	<0.01
			Personal Distress	.006	.000	.201	<0.01
			Perspective-Taking	.004	.000	.159	<0.01
			Empathic Concern	-.005	.000	-.170	<0.01
		Diversity	Fantasy	.004	.000	.114	<0.01
			Personal Distress	-.005	.000	-.150	<0.01
			Perspective-Taking	-.001	.000	-.025	<0.01
			Empathic Concern	.007	.000	.175	<0.01

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DISSERTATION PUBLICATIONS

Journal Articles

Alsager Alzayed, M., McComb, C., Menold, J., Huff, J., & Miller, S. R. (2020). Are you feeling me? An exploration of empathy development in engineering design education. *Journal of Mechanical Design (Under Review).*

Conference Papers

Alsager Alzayed, M., McComb, C., Menold, J., Huff, J., & Miller, S. R. (2020). Can Design Teams Be Empathically Creative? a Simulation-Based Investigation on the Role of Team Empathy on Concept Generation and Selection. In *ASME 2020 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*.

Alsager Alzayed, M., Miller, S. R., McComb, C. (2020). Composing empathic design teams: a simulation-based investigation on the role of personality traits and risk-taking attitudes on team empathy. In *the Ninth International Design Computing and Cognition Conference.*

Alsager Alzayed, M., Miller, S. R., McComb, C. (2020). Does empathy beget creativity? Investigating the role of trait empathy in idea generation and selection. In *the Ninth International Design Computing and Cognition Conference.*

Alsager Alzayed, M. (2019). An Exploration of the Role of Student Empathy in Engineering Design Education. In 2019 IEEE Frontiers in Education Conference (FIE) (pp. 1-2). IEEE.

Other Significant Publications

Alsager Alzayed, M., McComb, C., Hunter, S. T., & Miller, S. R. (2019). Expanding the Solution Space in Engineering Design Education: A Simulation-Based Investigation of Product Dissection. *Journal of Mechanical Design*, *141*(3).

Starkey, E. M., **Alsager Alzayed, M. A**., Hunter, S., & Miller, S. R. (2020). Dissection Versus Incubation: The Within-Subject Effects of Product Dissection Activities on Design Variety. *Journal of Mechanical Design*, *142*(1).

Starkey, E. M., **Alsager Alzayed, M**., Hunter, S. T., & Miller, S. R. (2018). Confidently Exploring the Solution Space: The Within-Subject Effects of Product Dissection on Design Variety and Creative Self-Efficacy. In *ASME 2018 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*.

Alsager Alzayed, M., McComb, C., Hunter, S. T., & Miller, S. R. (2018). Helping Teams Expand the Breadth of Their Solution Space Through Product Dissection: A Simulation Based Investigation. In *ASME 2018 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*.

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