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Traditional disciplinary silos have separated engineering and the humanities, creating gaps in engineering students' skills. Technical knowledge and aptitude have long been a mainstay in engineering education, whereas critical thinking, empathy, and ethical reasoning have been key in the humanities. In an ever complex and interrelated world, society's grand challenges call for problem-solving that provides technical innovations while considering and understanding the people involved and affected by that innovation. A holistic outlook, combining engineering with the humanities may be an avenue to enrich the technical skills of engineering students while developing their empathetic skills. Based on this idea, a collaboration between Texas Tech University (TTU) and the Rochester Institute of Technology (RIT) has been made to analyze problem-solving assignments in interdisciplinary team-taught (ITT) courses and regular engineering courses. The ITT courses are called humanities-driven science, technology, engineering, and mathematics (HDSTEM) because they take the structure and form of a humanities course while introducing and discussing STEM problem-solving. Early-in- and late-in-semester surveys for empathy and critical thinking were given for all courses in this study. Further, discourse analysis of problem-solving assignments from HDSTEM and engineering courses was performed. A commonly used rubric for empathy was used in conjunction with this analysis to gauge and baseline students' empathetic dispositions. Results from surveys show no statistically significant difference in empathy or critical thinking levels among students in all treatments, which is understandable based on the limited number of surveys collected. Preliminary results from discourse analysis indicate improved empathetic dispositions are greater in problem-solving assignments in HDSTEM courses regardless of group (i.e., institution). Further, with the curricular treatment of HDSTEM, specifically asking students to empathize before their problem-solving assignment can improve the empathetic dispositions of students. This work is based on work from an NSF Improving Undergraduate STEM Education (IUSE) grant.

Introduction

Science, technology, engineering, and mathematics (STEM) majors need to understand the challenges they will face as professionals and the communities they will serve. Studying the humanities as part of professional preparation will ground scientific and technological innovation in a context of human need and reaffirm the ethical imperatives that inform the speed, impact, and consequences of human progress. There are natural connections between the humanities and STEM, which can deepen students' educational experiences [1]. Yet, there has been a long-standing tension in STEM education between developing technical knowledge and interpersonal skills [2]. For example, it is recognized that the humanities have played little or no role in engineering courses [3], and most institutions deliver these curricula through different departments/faculties/schools. Most STEM curriculums emphasize technical knowledge without concern for the social implications or the historical and social contextualization of science and technology in our modern world and our shared global past. This has led to the development of pedagogical approaches designed to promote the training of engineering students as specialists in their narrow disciplines while relegating the study of humanities to the "soft skills" involved in interpersonal relationships [2].

The humanities ground scientific and technological innovation in a context of human need and reaffirm the ethical imperatives that inform the speed, impact, and consequences of human progress. By reasserting the importance of humans and human impact in science and engineering and recognizing the social, political, and cultural outcomes, STEM students will be better prepared for the 21st century. Through humanities-driven STEM (HDSTEM), students will not simply develop technically accurate solutions, but they will question the impact of their ideas on society, or, as Bourdeau and Wood [4] state, "students will blend the study of science, technology, engineering, and mathematics with interest in, and concern for, human affairs, welfare, values, or culture." With HDSTEM, students are asked to draw comparisons between the period under investigation and the technical engineering work of today. They must consider the human experience throughout the process. Questions that follow then become commonplace in STEM learning: Under what conditions does this solution serve the human condition? Does the solution serve diverse populations in an equally positive manner? Can the solution be redesigned to serve the population of interest better? Could this solution have a negative impact on the population it is designed to help? Asking and answering these questions during problem-solving shows a developed empathetic disposition for students, and with these questions, a cultivation of empathy can be ascertained.

Background

Humanities and STEM. Blending STEM with the humanities can aid students in developing creativity, innovative thinking, and communication skills [5, 6]. This blending has been done by simply humanities modules into STEM coursework [7]. Embedding modules has given STEM students a better understanding of how science and engineering carry social impacts more so than traditional courses [8]. These impacts are seen in the design process [9, 10] and in other contexts [11-14]. More importantly, implementations of the humanities within STEM can provide the context for problems that could be left out in stand-alone STEM courses. Particularly, the humanities present the social challenges. These same social challenges must be considered with technical challenges in problem-solving for STEM professionals.

Empathy and Critical Thinking. Social challenges are ever present in our society, requiring STEM professionals to empathize and critically think with and for numerous stakeholders. Paul and Elder [15] suggest that "to reason justifiably through an issue, you [sic] must identify points of view relevant to the issue and enter them empathically" (p. 28). The argument is that with the development of what Lloyd and Busby [16] call "intellectual empathy," students can move beyond the narrow scope of their own thinking and weigh more possibilities as they consider others' dispositions and beliefs when solving a problem. Paul and Elder [15] offer a similar sentiment, suggesting that students often consider problems as having a finite number of solutions. The number of possibilities is expanded, they argue, when students are taught to empathize or view the problem from another's point of view, asking, "what if?" Empathy is then seemingly related to critical thinking because it allows students to consider a greater number of approaches when solving a problem.

How empathy and emotional intelligence play a role in the development of critical thinking skills has not been well studied [17, 18]. This is especially concerning given that studies suggest strong connections between rational judgement and critical thinking [19, 20]. In fact, Lloyd and Busby [16] further argue that the question, "what if," is also tied to ethical decision-making. "What if" leads students to think about the consequences of their choices. Within STEM literature, there is little consensus on what, precisely, constitutes ethical consideration. Bairaktarova and Woodcock [21] suggest it ties to Kohlberg's stages of moral reasoning, whereas Harris Jr, et al. [22] claim ethics is separate from morality in that ethics is not a universal concept like morality; as it refers to standards of specific fields or disciplines. Some have argued ethical considerations must include emotional consideration, especially related to others or the general public [16, 23, 24]. Emotional consideration of others and the desire to reach an agreement with others constitutes what might be considered the basis of ethical decision-making. Roeser [23] explains determining what is agreeable to groups of individuals cannot exist without a mixture of critical and empathetic reasoning: "rational reflection would not be able to provide us with the imaginary power that we need to envisage future scenarios and to take part in other people's perspectives and to evaluate their destinies" (p. 106).

STEM and Empathy. Through emotional reflection, STEM professionals come to decisions about how their choices affect individuals beyond themselves. STEM curriculum alone often fails to teach this important concept [25-27]. Humanities instruction may be key to supporting these types of reflections. Prior research indicates that interdisciplinary and holistic approaches may be more effective than traditional programs in developing empathy [28-30]. Through instructional modeling, team-teaching among humanities and STEM instructors can encourage the development of these skills [29]. With HDSTEM, we propose an innovative, holistic approach emphasizing the humanities as part of STEM education. We seek here to develop critical thinking and student empathy through the analysis of problem-solving assignments and surveys from students enrolled in HDSTEM courses and compare similar assignments and surveys of students enrolled in an introductory engineering course.

Courses and Assignments

RIT and TTU Courses. During the fall of 2022, three courses were carried out where problem-solving assignments were analyzed. Two HDSTEM courses, one titled "HONS 1301: War, Machine, Culture, and Society: History and Engineering in the Second World War" at TTU and one titled "HIST 255: History of World War II" at RIT, were team-taught courses that paired an engineering instructor with a history instructor. Within the context of the history of the Second World War (WWII), engineering and scientific principles were discussed and used in problem-solving assignments. As a comparison, an engineering course titled "ME 2207: Engineering Design Graphics" was taught by a single engineering instructor at TTU. Similar problem-solving assignments were introduced in ME 2207 that pertained to engineering principles and, more specifically, engineering graphics.

Problem-solving assignments. In total, four problem-solving assignments in both the HDSTEM and regular engineering courses were analyzed. The problem-solving assignments were based on Six Sigma's Define, Measure, Analyze, Implement, and Control (DMAIC) model, with some assignments altered with an additional Empathize step (i.e., EDMAIC). The DMAIC model is introduced at the start of the semester, and the first problem-solving is to follow the DMAIC model. Following the first assignment, an empathize step asks the students to consider the society, culture, and people involved in their problem before solving with DMAIC. The second and third assignments follow this EDMAIC format. The fourth assignment allows the students to do either DMAIC or EDMAIC. The structure of the problem-solving assignments allows for comparison:

- Across demographically different institutions with a university-wide offering (RIT) to an honors offering (TTU)
- Between course treatments team-taught interdisciplinary course (HDSTEM) and a regular engineering course (ME 2207)
- Between assignments with basic problem-solving methods (DMAIC) and in problem-solving methods requiring an empathize step (EDMAIC)

The first assignment for WWII courses covers problems and issues during the Great War (WWI). WWI is a natural starting point for discussing WWII with many of the same countries and combatants involved. WWI also provides a valuable learning experience in warfare that many of these combatants are influenced by in the build-up and start of WWII. To introduce the DMAIC process, the problems with trench warfare and the static nature of WWI are discussed. Class discussion of these problems leads to the tank's solution, which carries many measures, alternatives, and controls with it. With a worked example, students are tasked with finding another problem and solution to reverse engineer during WWI for their first assignment and following the DMAIC method. Students can choose problems that interest them and can cover technology, tactics, logistics, and medical issues from the time period.

Students must determine a problem on their own in all the assignments. The time period is one changing factor in the assignments. For example, the second assignment tasks the students to reverse engineer a solution from the Interwar Period. While this may consider peacetime problems before WWII, students may also consider wartime problems from the Spanish Civil War, which occurs during this period. Along with this change in the time period, the students are also asked to empathize with their DMAIC. The empathize step posits a number of questions for the students to consider including: What is the societal need for the solution; what are the societal constraints/freedoms; what are the lives of the creators, users, and/or others like; what is their "average" day like; and what challenges do they face? These same questions are used in the third assignment, which splits students into groups. One group covered the attack on Pearl Harbor, and the other group covered the Normandy Invasion. Both of these events involved the start of the United States' involvement in WWII, and problems from these can include technical and logistical issues from the planning of attacks and defense to actual issues on the ground during these conflicts.

The fourth and final assignment reverts back to a simple DMAIC. With it, students are allowed to consider any problem from the start of the United States' involvement in WWII to the end of WWII, particularly with the development and use of the atomic bomb. In the assignment, a list of topics is provided for students to consider, including the development of the atomic bomb, Hunter-Killer groups, time of air operations, aircraft repair planning and operations, aircraft paint schemes, submarine operations, and battle planning and strength of military forces. These topics relate to course lectures, such as operations research, game theory, and nuclear science. Students are free to choose similar topics that are not listed.

As with the WWII course, the assignments follow the topics discussed during the Engineering Graphics course. Being an engineering course, the context of these assignments is different. Engineering Graphics teaches students how to create, display, and interpret designs within standard engineering contexts, particularly in orthographic projections and detailed drawings. The overarching purpose and intent of Engineering Graphics are to communicate ideas and designs graphically. The problem-solving assignments provide students with a written means to do this. While not being related to a specific time period like WWII, the first DMAIC assignment and second EDMAIC assignment were devised for the Engineering Graphics course based on introducing and practicing DMAIC, with the first assignment being a DMAIC to solve being marooned on a deserted island, and an EDMAIC based on personal problems the students may have with traveling to class as means to introduce DMAIC. This EDMAIC gives students the opportunity to consider their problem and how it can relate to other students, faculty, and administrators that traverse in and around campus to get places. The third and fourth assignments relate to the course project for the Engineering Graphics course. This project has students design, model, prototype using 3D printing, and assemble a battery-powered toy car. From this project, their EDMAIC asks them to consider problems and issues in the automobile design industry. The ending DMAIC asks them to discuss a problem in the design and manufacture of their car.

Surveys and Discourse Analysis

Early in each course, students were asked to complete critical thinking and empathy surveys. The RIT Applied Critical Thinking Survey (RIT ACTS) comprises 16 questions to be answered on a 5-point scale from “Never” to “Always.” RITs ACT survey asked the following questions prefaced with “Thinking about the course that you indicated in the above question, how often have you”:

1. Evaluated the quality and credibility of a source of information.
2. Weighed the importance of information for your needs.
3. Examined strengths and weaknesses of a source of information.
4. Assessed the quality or relevance of a source of information based on your knowledge of mathematics or statistics.
5. Learned something that impacted your view on a topic.
6. Considered diverse perspectives or different views to develop your thinking.
7. Looked for or were aware of potential biases or assumptions in your views or others' views.
8. Connected ideas from many experiences, including courses to inform your thinking.

9. Sought expertise from others to gain understanding.
10. Analyzed alternate theories, methods, or strategies to address complex problems.
11. Considered the larger context of an issue or problem and the potential impacts of solutions.
12. Evaluated strengths of conclusions by examining lines of reasoning.
13. Generated and evaluated the effectiveness of new ideas to address real-world problems.
14. Developed a framework or methodology to manage experimental of novel approaches.
15. Managed contingencies or unexpected events or results.
16. Produced results that are effective, appropriate to the challenge, and/or address stakeholder needs.

The Gaumer Erickson, et al. [31] Empathy Scale comprised 15 questions to be answered on a 5-point scale "Not very like me" to "Very like me." Questions per Gaumer Erickson, et al. [31] include (N indicates reverse coded items):

1. I try to see things from other people's points of view.
2. When I don't understand someone's point of view, I ask questions to learn more.
3. When I disagree with others, it's hard for me to understand their perspective. (N)
4. I consider people's circumstances when I'm talking with them.
5. I try to imagine how I would feel in someone else's situation.
6. When someone is upset, I try to remember a time when I felt the same way.
7. When I'm reading a book or watching a movie, I think about how I would react if I was one of the characters.
8. Sometimes I wonder what it would feel like to be in my parents' situation.
9. When a friend is upset, I try to show them that I understand how they feel.
10. I say things like "I can see why you feel that way."
11. I've been known to say "You are wrong" when someone is sharing their opinion. (N)
12. When a friend or family member is sad, my actions let them know I understand (like a hug or a pat on the back).
13. I say things like "Something like that happened to me once, I understand how you feel."
14. I've told my friends things like, "You shouldn't be upset about that" or "Stop feeling that way." (N)
15. When I know one of my friends is upset, I try to talk to them about it.

These scales were repeated during the last week of the course. Each student's ratings for all items on each scale were aggregated to compute a 'Critical Thinking' and 'Empathy' score, with higher values indicating greater perceived critical thinking and empathy in each case.

As an additional step to consider empathy, we have engaged in discourse analysis of student assignments. Discourse analysis is a methodology that closely examines an individual's language to learn more about one's thought patterns, beliefs, values, and identities [32, 33]. Specifically, we were interested in the ways that students used language within their assignments to position themselves empathetically. We used four assignments that students completed over the course to look for changes in how they expressed themselves linguistically that might indicate a greater capacity for perspective-taking and empathizing.

Results

The maximum score for the RIT ACTS is 80 (See Figure 1 and Figure 2) and 75 (See Figure 3 and Figure 4) for the Empathy Scale. A total of 15 students completed the RIT ACTS on both occasions, with 16 completing the Empathy Scale. There were 4 completed surveys from students in the TTU Engineering Graphics course versus 11 or 12 taking the HDSTEM WWII history course at either university. Quantitative comparisons were made, but any conclusions are limited at this point by the small number of student participants.

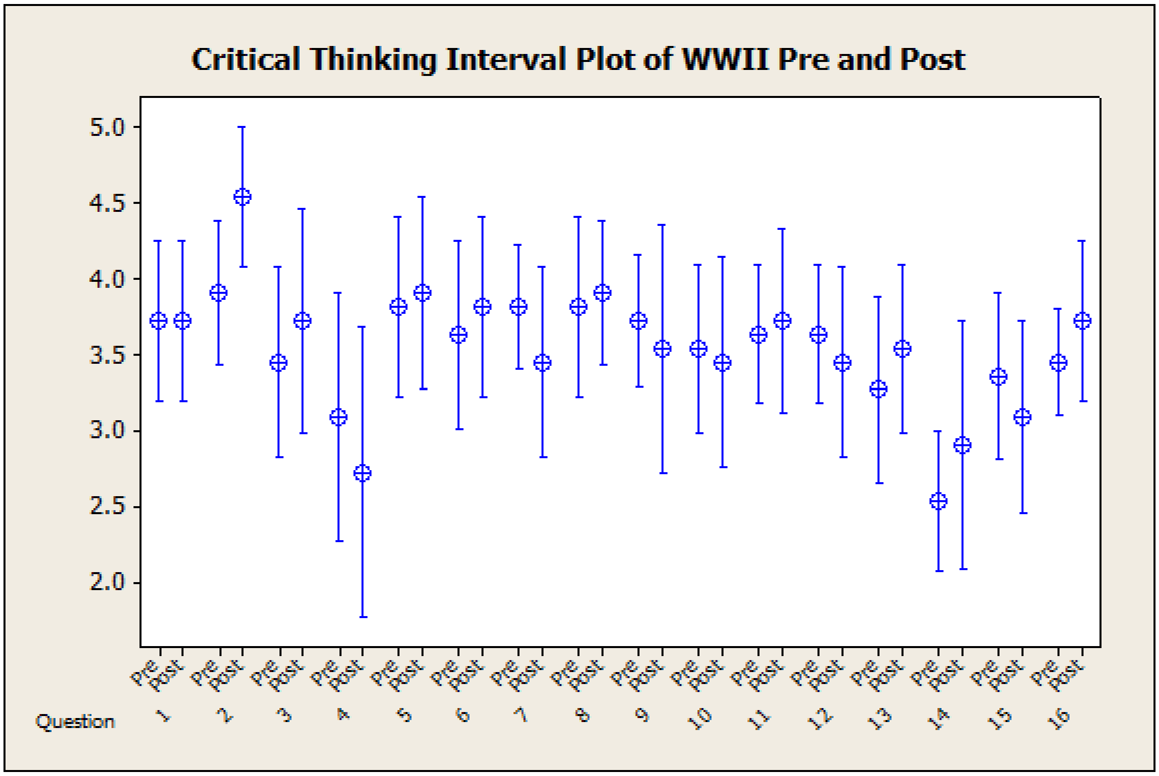

Figure 1: Pre and Post Scores per Critical Thinking Question for WWII Participants

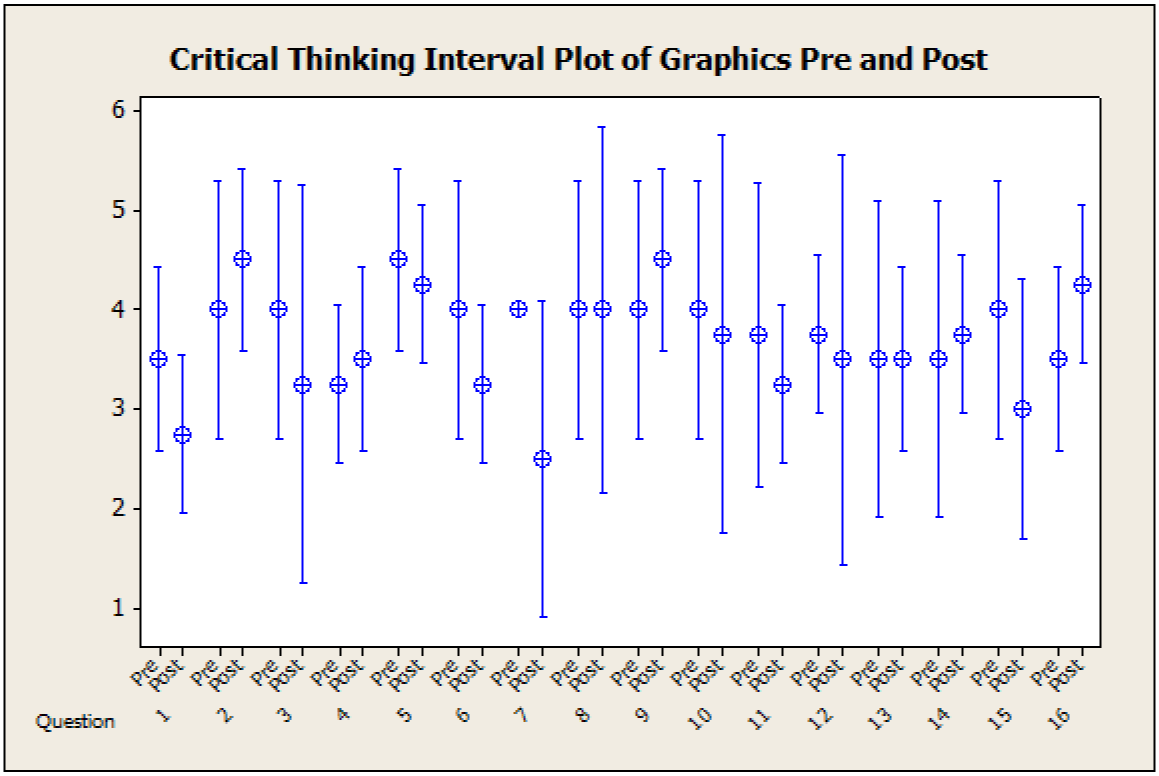

Figure 2: Pre and Post Scores per Critical Thinking Question for Graphics Participants

Overall, average scores for the RIT ACTS were 57.3 (SD = 7.6) early in the course versus 57.7 (SD = 5.3) late in the course, and these were not significantly different (*t* <1, paired test in all cases). Looking at only the 11 students in the WWII course revealed the same lack of significant difference. The same pattern was observed for the Empathy scale, where the average was 53.9 (SD = 6.7) early in the course versus 54.9 (SD = 6.4) late in the course (*t* ~ 1). Again, the 12 students completing the Empathy scale in the WWII course didn't differ significantly *t* = 1.2, *p*>.1), but the data suggest there is a small increase in Empathy scores for this group. It is unsurprising that a small sample would produce non-significant differences and more importantly, we would not see self-report scores change based on two measures 13-14 weeks apart from a single course.

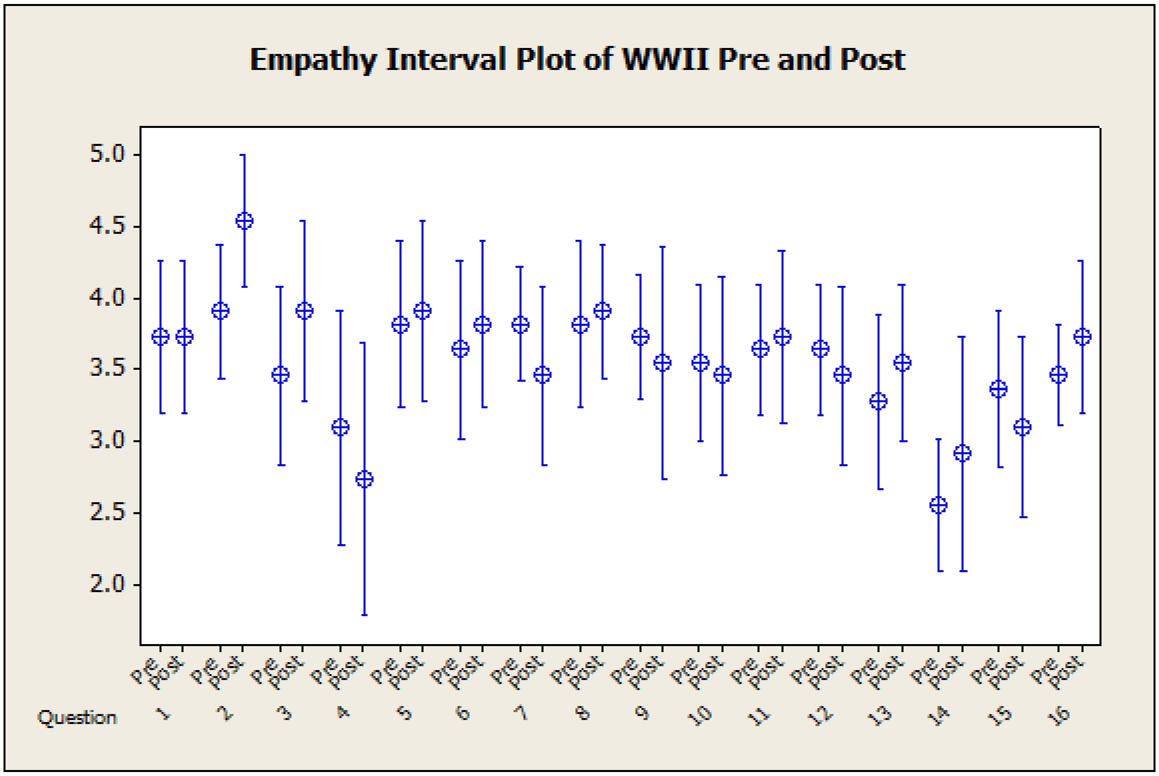

Figure 3: Pre and Post Scores per Empathy Question for WWII Participants

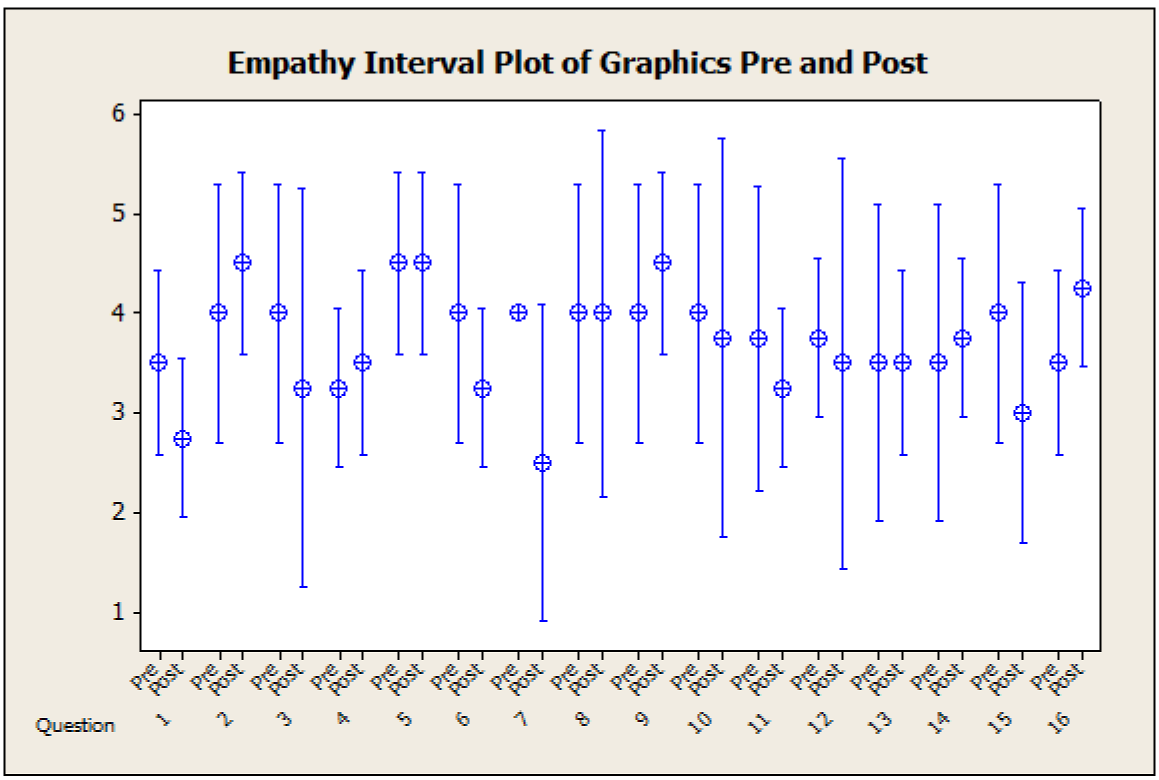

Figure 4: Pre and Post Scores per Empathy Question for Engineering Graphics Participants

Discourse analysis provides a more revealing qualitative approach and analyzes the students' DMAICs (i.e., the first and fourth assignments). Several patterns were revealed across both RIT and TTU student writing. These patterns suggested that students developed more empathetic positions as the course progressed. For instance, one pattern was the use of human-centered language in their later assignments. Consider simply the difference between "bullets needed to be traceable" versus "soldiers needed to be able to trace bullets" during night skirmishes. Here, we see that there is a greater focus on a human experience and needs of the latter, and it places the reader in the position of another human being, at least in a greater capacity than the former sentence. We also saw a greater discussion of human motivation behind inventions and decisions in later assignments. Whereas students in the earlier assignments focused on technical requirements to make something work, and sometimes focused on winning the war, later assignments described what was at stake for nations and individuals.

Based on the lengthy analysis, we cover the discourse analysis of the WWII courses more deeply in our presentation [34]. However, we feel it suffices here to acknowledge that both the length of student writing and the ways that students approached their writing changed by the end of the course in such a way as to add more detail and focus more heavily on experiences during the war. Discourse analysis of Engineering Graphics assignments is in-process. With the small number of participants, there are limited conclusions that can be drawn on the comparison between the HDSTEM treatment and Engineering Graphics treatment at this point. There is some anecdotal evidence that supports similar effects in regard to empathetic language and dispositions in the Engineering Graphics course, but these effects may be limited due to the content and context of the course.

Conclusion

While no statistically significant results are seen in survey materials, preliminary results through discourse analysis have shown changes in critical thinking and empathetic dispositions in assignments for the HDSTEM treatment. When asked to empathize in the EDMAIC assignments, students can consider more carefully how they define and who they consider in the define step of the DMAIC. This is seen in both treatments of HDSTEM and regular engineering courses. Furthermore, comparing the bookend DMAIC assignments, empathy scores indicate an improvement over the course of the semester suggesting that asking students to empathize in EDMAIC assignments changes students' perceptions resulting in developed empathetic dispositions in standard DMAIC assignments. This result is seen more clearly in the HDSTEM treatment. Finally, no discernable difference was seen in the treatment between TTU and RIT. This is promising for furthering the HDSTEM curriculum, which was introduced at RIT in the fall of 2022 and has been a part of TTU Honors curriculum since the fall of 2018, as a transferable and scalable implementation. However, it is important to note the preliminary nature of this work, and the need for further course build-up and analysis. Overall, empathetic dispositions in engineering students can be cultivated by asking them to empathize in their problem-solving endeavors. Further, the humanities with integrated STEM problem-solving can provide optimal gains in empathic dispositions for engineering students.

Implications from this preliminary work do show promise. The simple implementation of asking students to empathize before or during the problem-solving process could be a simple addition to current engineering curriculum and design. Further, the process of writing should be instituted more in engineering curriculum because it gives students a voice that can illustrate their thinking and feelings. Discourse analysis can be used to better understand this thinking and these feelings, but may not be entirely justified based on the many positive effects writing can give students, including in critical thinking and empathetic disposition. Empathy, while argued as an innate skill or ability, is something that should be cultivated and practiced in engineering. This is readily apparent by the benefits that things like empathetic design and problem-solving create. The ever complex and changing world requires solutions that meet the needs of society in a fair and equal way. Understanding the conditions and feelings of others through empathy will be key for this. The ties between empathy, ethical reasoning, and critical thinking further show how benefits can be wholesale in engineering applications.

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