WIP: Comparing Engineering and Humanities Student Approaches to Complex Problem Solving

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***Abstract*—This work-in-progress research paper contributes new insights into the qualitative differences in conceptualization and problem-solving approaches between engineering and humanities students in a scenario-based complex problem. We interviewed 14 undergraduate students at Purdue University, comparing their levels of complexity in conceptualization and problem-solving approaches. The first round of coding suggested that students' academic disciplines had some impact on the complexity of their problem-solving approaches. We are currently conducting a second round of in-depth analysis to understand what types of educational experiences encourage systems thinking. The results can inform the development of engineering courses that aim to develop systems thinking.**

Keywords—Systems Thinking, Problem Solving, Student Assessment, Competence.

I. Introduction

With the growing complexity and connectedness of engineering problems, engineering students need to develop systems thinking to solve ill-structured problems that are socially contextualized [1], [2], [3]. Systems thinking is the ability to see the world as a complex system consisting of a web of interconnected, mutually influential systems [4], [5]. Previous work has found limited opportunities to develop systems thinking within traditional engineering curricula [6]. One approach that may help engineers develop systems thinking is integrating humanities topics and methods into engineering courses [7], [8]. Given the positive effect of a humanities-engineering approach to enhance systems thinking, we examined how undergraduate students in engineering and humanities disciplines conceptualize and approach complex problems, as well as how their individual characteristics affect their problem-solving approaches. In this study, we addressed three research questions: (1) How do undergraduate students from engineering and humanities majors conceptualize a complex problem? (2) How do undergraduate students from engineering and humanities majors approach solving a complex problem? (3) How do students' academic disciplines relate to the problem conceptualization and problem-solving approaches?

We interviewed 14 engineering and humanities undergraduate students to understand their approaches to a complex problem presented in a written scenario (Lake Urmia scenario). Our preliminary coding results revealed that students' disciplinary backgrounds had some impact on the levels of complexity in their conceptualization of and approach to solving the problem, for which students in engineering disciplines had less complex problem-solving approaches than those with humanities backgrounds.

II. Background

Engineering programs have focused on teaching engineering students technical and theoretical knowledge and solving well-structured problems in classrooms, yet not traditionally preparing students to solve real-world, ill-structured problems [3], [9], [10]. As real-world problems become more complex, engineering students need to develop systems thinking to be able to address such problems [1], [2]. Complex problems are open-ended, ill-structured, and situated in specific contexts [11], [12]. Solving such problems involves addressing the technical and social dimensions of the problems [13] while considering the intersection of these dimensions within the specific, local context [7]. Systems thinking, which enables engineering students to perceive the world that consists of a network of interconnected systems, each with components that potentially impact one another and that shape the system [4], [5], is useful for understanding and solving complex problems. A key aspect of systems thinking is connecting technical and contextual components of a problem [13], [14], [15]. Studies have found that systems thinking can be developed through experience or intervention [7], [16], [17], such as exposure to visual technology and experience with system modeling.

Integrating humanities approaches into engineering education has been shown to support students' systems thinking development [7], [8]. Engineering as a discipline applies science and mathematics concepts to real-world settings, which inherently connects engineering work to the human experience [18], [19], [20]. Humanities disciplines provide approaches for understanding the human experience that can inform this aspect of engineering work. Prior research has suggested that knowledge of and experiences with humanities can enhance intellectual flexibility [21], understanding of engineering problems [22], ability to consider social issues [23], and ability to consider unintended consequences of engineering solutions [24]. Building on this prior work, we have presented a conceptual model for how humanities approaches can inform engineering problem solving which can be used to develop pedagogical interventions [7]. Preliminary evidence from two recent studies suggests that students developed specific aspects of systems thinking through taking an interdisciplinary humanities-engineering course [7], [8].

Although we see the potential for humanities-informed engineering education, we wanted clearer evidence for differences in the learning outcomes between humanities and engineering educational approaches. Prior research studies have suggested that humanities students may think differently about complex problems than engineering students. These include examining differences across disciplines in students' perceptions of their development of creativity [25], [26] and critical thinking [27]. While both engineering and humanities students valued creativity [28], Daly et al. [25] found that humanities students perceived their curriculum to be impactful for their development of creative skills, while engineering students perceived their curriculum to have little impact on [25] and few opportunities for creative skill development [26]. In addition, Bumbaco and Douglas [27] revealed that humanities students viewed critical thinking through the lens of forming opinions and supporting them with arguments while engineering students viewed critical thinking through the lens of applying engineering concepts and problem-solving. On the topic of systems thinking, one prior study has suggested that engineering graduate students with multidisciplinary experience scored higher on the Capacity for Engineering Systems Thinking assessment [29]. Other studies have compared engineering students with engineering practitioners, but not with students of other disciplines (e.g., [13], [15]). For studies that compared student learning across disciplines, they have largely focused on students' perceptions and self-ratings on surveys, rather than exploring how they approached a complex problem. Therefore, we aim to fill this gap by comparing engineering and humanities students' approaches to solving complex problems. Addressing this question can provide insights into the types of educational experiences that develop systems thinking, and therefore inform our development of engineering courses to achieve this outcome.

III. METHODS

We conducted semi-structured interviews using a scenario developed by Davis et al. [30] to understand how college students think about complex problems. We qualitatively characterized approaches that students used to conceptualize (RQ1) and approach solving the problem (RQ2). We then considered how students' majors related to their problem conceptualization and problem-solving approaches (RQ3).

A. Participants

We recruited participants by contacting student organizations and academic departments related to engineering and humanities at Purdue University (e.g., Political Science Department, Society for Biological Engineering). We asked the leaders of these groups to share a recruitment email with their members. We interviewed 14 undergraduate students at Purdue University, including six engineering students, six humanities students, and two students who majored or minored in both engineering and humanities disciplines. We believe a sample size of 14 participants is appropriate for this exploratory study based on the concept of information power, which suggests that sample size in qualitative research is related to the aims of the study, specificity of the sample, use of theory, depth of dialogue, and intended analysis [31]. Our study has a narrow aim (i.e., focusing on a specific task), targets a specific sample (i.e., college students in specific disciplines), and builds on existing theory (i.e., using previously developed scenario). Our sample is therefore sufficient to address our research questions. The engineering students studied varying majors (e.g., computer, mechanical, robotics, and aerospace engineering). Similarly, the humanities students also varied in their specific majors (e.g., theater, communications, anthropology, political science). Of the students who studied both disciplines, one was enrolled in the environmental and ecological engineering major and a minor in sociology and global engineering studies. The other student was enrolled in two majors, mechanical engineering and Spanish. Participants consented to participate and were paid $20 for their participation. The university IRB office approved the study.

B. Data Collection

We used a semi-structured interview protocol to understand how college students think about complex problems. First, we shared with the participants a written and a video version of a scenario that described a complex problem. Students reviewed and reflected on a scenario for 10 to 20 minutes. We encouraged them to take notes or draw pictures to help them process the scenario. We then asked participants about their educational background, perceptions of the problem, approaches to developing a solution to the problem, prior experiences that informed their ways of thinking, typical steps to address complex problems, and their understanding of the characteristics that make a problem complex. Two interviewers conducted one-on-one interviews over Zoom; interviewers received training through shadowing a mock interview conducted by an experienced interviewer. The interviews lasted 30–60 minutes. At the end of each interview, students were asked to email researchers a copy of any notes they took during the task, which helped the research team to understand their responses in more detail.

C. System Thinking Assessment Tool: Lake Urmia Vignette

To address the research questions, we used a scenario describing a complex problem developed by Davis et al. [30] to discover and compare Engineering and Liberal Arts undergraduate students' problem conceptualization and problem-solving approaches at Purdue University. The scenario aligned with the research goals because it was designed to capture students' understanding of the complexity of problems in socio-environmental systems. It describes a real-world scenario and includes a short vignette about a drastically shrinking lake in Iran and the ecological disaster.

D. Data Analysis

We transcribed the interviews using Otter.ai, an AI-powered transcription service [32]. Two interviewers reviewed and corrected the transcripts. Then, the research team analyzed the transcripts to evaluate the participants' levels of complexity in problefm conceptualization and problem-solving approaches. To address RQ1 and RQ2, we used holistic coding. Holistic coding involves assigning a code by considering the data as a whole, which in this case involves assigning one code per transcript for each research question. This coding method is often used as a first-round coding approach [33]. In this analysis, each researcher developed holistic codes identifying three levels of complexity for conceptualization (RQ1) and problem-solving approach (RQ2). Each researcher summarized their perception of each participant's problem conceptualization and problem-solving approach, assigned codes to each participant, and identified representative quotes. Then, the researchers discussed the codes, developed a final codebook, and reached a consensus on the definitions for each level of complexity and the code for each participant for RQ1 and RQ2. To address RQ3, we examined the participants' conceptualization and problem-solving complexity considering their academic background: (1) engineering, (2) humanities, and (3) engineering and humanities.

E. Limitations

First, although the LUV allowed for a more direct assessment of systems thinking than self-report surveys, the data represent students' reports of what they would do in a situation and not observed behaviors in real-life situations. The data may reflect students' idealized or socially expected responses. Second, some participants may have been motivated by compensation rather than a desire to give thoughtful responses. Third, online interviews could influence participants' responses, as the online format may be less engaging than in-person interviews.

IV. RESULTS

Overall, the coding yielded different categories of participants based on their demonstrated complexity in problem conceptualization and problem-solving approaches. Most participants demonstrated intermediate levels of complexity for RQ1 and RQ2. These coding results can be found in Table I.

TABLE I. PARTICIPANTS' DEMONSTRATED LEVELS OF COMPLEXITY

	Level 1 - Simple	**Level 2 - Intermediate**	**Level 3 - Complex**
RQ1 Problem Conceptualization	4, 5, 11	1, 3, 6, 7, 8, 9, 12, 14	2, 10, 13
RQ2 Problem-Solving Approach	3, 6, 8, 11, 12	1, 4, 5, 10, 13, 14	2, 7, 9

A. RQ 1: How do undergraduate students from engineering and humanities majors conceptualize a complex problem?

Based on the analyses, the three levels of the complexity of problem conceptualization were defined:

- Level 1 (Simple): Recognizes basic problem elements, focusing on selective or obvious facts without deeper analysis. Often conceptualizes the problem as having one core issue.
- Level 2 (Intermediate): Identifies causes and implications, but there is an absence of the interrelation among causes and implications.
- Level 3 (Complex): Shows deep understanding of many aspects of the problem (e.g., environmental, socio-economic, political, ethical, and technical aspects) and their interrelations.

Table II shows representative quotes from participants to provide evidence for how the different levels of problem conceptualization looked in responses to the LUV scenario. For example, Participant 4 demonstrated simple problem conceptualization because the participant recognized some main aspects addressed explicitly in the vignette (e.g., health issues, societal implication, governmental actions), but the participant lacked deep analysis of variables or connections beyond those that were provided. In contrast, we coded Participant 2 at a complex problem conceptualization because the participant not only demonstrated an understanding of problems and causes in the LUV scenario but also delved into socio-economic, political, and ethical implications, which were evident in the representative quote in Table II.

TABLE II. SAMPE QUOTES FOR PROBLEM CONCEPTUALIZATION

Levels of Complexity	**Representative Quote**
Level 1 - Simple	"The main issues [are] the water level, that's just low... due to the water level being low, there's salt that's being able to... cause respiratory illnesses or cancer, higher infant mortality... it's more of a societal issue... the government is... cautious or taking a little bit more time to come to their decision than most people would like." - Part. 4
Level 3 - Complex	"The first part is like, big corporations tend to cause severe crises... Second part is people… we have billions of people now and so in a culture of consumerism... Third, the government typically is the one who is expected to create regulations, but these don't often stick... the scenario doesn't explicitly mention who does the building. I mean, for all I know, it could even be like a community of people." - Part. 2

B. RQ 2: How do undergraduate students from engineering and humanities majors approach solving a complex problem?

Based on the analyses, the three levels of the complexity of the problem-solving approach were defined:

- Level 1 (Simple): Takes one perspective to solve the problem, limited in the number of stakeholders considered, or very limited in the process described.
- Level 2 (Intermediate): Considers several stakeholders but not a process to address the problem, or only a process but not a diverse set of stakeholders.
- Level 3 (Complex): Involves diverse stakeholders and outlines a joint problem-solving process, including multiple approaches or progress-tracking mechanisms.

Table III shows representative quotes for problem-solving approaches in level 1 and level 3 to provide evidence for how the different levels looked in student responses. We coded Participant 3 at a simple problem-solving level because Participant 3 focused mainly on trying to build awareness of the issue, educating the public, and offering scientific evidence to justify the decisions, but the approach to problem-solving was limited to a broad goal of "restoring the lake." In contrast, we coded Participant 5 at a complex problem-solving level because Participant 5 considered a broad range of stakeholders and presented a process of gathering insights from these stakeholders to inform a solution, followed by data collection to track progress and adjust plans.

TABLE III. SAMPLE QUOTES FOR PROBLEM-SOLVING APPROACHES

Levels of Complexity	Representative Quote
Level 1 - Simple	"Getting group of people together to kind of brainstorm what exactly the problems are. And like, let's try to narrow down what we want to focus on first, because we can't really tackle everything at the same time, we just have to kind of go step by step. So I feel like the first thing would be like, let's focus on restoring the lake again. But also having these reasons to backup why we need to focus on that, which is like the health issues, maybe we could later on focus on like, why environmentally, it's important to restore it." - Part. 3
Level 3 - Complex	"So I would do research. And then I would evaluate that research. And then based on the evaluations…, I would attempt to implement policy or just implement change, just relative. And I would analyze and evaluate after I've implemented something, see how that has changed it. And based on evaluations, I would, I don't know, I guess compare. Like has anything changed? Has it has decreased even more, has it gotten slightly better?" - Part. 5

C. *RQ 3: How do students' academic disciplines relate to the problem conceptualization and problem-solving approaches?*

To address RQ3, we looked for patterns between students' academic disciplines and their problem conceptualization (PC) and problem-solving approaches (PSA). The findings are somewhat aligned with our hypothesis that students' academic disciplines are related to their approaches. While we did not find differences in PC between disciplines, we found two interesting patterns in students' PSA as shown in Table IV. First students who majored in engineering disciplines were more likely to have simple problem-solving approaches (Level 1) than those who majored in humanities disciplines or both engineering and humanities disciplines. Second, students with humanities backgrounds (Humanities and Engr & Hum) were the only ones with complex PSA (Level 3).

TABLE IV. LEVELS OF COMPLEXITY IN PROBLEM CONCEPTUALIZATION AND ASSOCIATED DISCIPLINES

	Problem Conceptualization			Problem-solving Approach		
Disciplines	**Level 1**	**Level 2**	**Level 3**	**Level 1**	**Level 2**	**Level 3**
Engineering	1	3	2	3	3	0
Humanities	2	3	1	1	3	2
Engr & Hum	0	2	0	1	0	1

V. IMPLICATIONS AND FUTURE DIRECTIONS

We investigated how students' academic disciplines were related to problem conceptualization and problem-solving. We found engineering and humanities students did not vary in their complexity of problem conceptualization, but there was variation in approaches to solving the Lake Urmia scenario. In response to RQ1 and RQ2, we identified three different levels of complexity for how students conceptualized and solved the problem. We noted that students might have a complex problem conceptualization, but a less complex problem-solving approach, and vice versa. In response to RQ3, we found students with humanities backgrounds are more likely to have complex problem-solving approaches than those solely in engineering disciplines.

Our findings contribute new insights to the literature on complex problem solving. First, similar to earlier studies (i.e., [13], [15]), we found that engineering students tended towards less complex problem-solving approaches when addressing our scenario (Levels 1 and 2). However, we contribute a new perspective by considering problem conceptualization separately, where we found that the engineering students were equal to the humanities students in thinking about the complexities of the problem. Second, our findings contribute insights about the potential impacts of differences across disciplines in student perceptions of critical thinking [27] and creative skills [25] that have been found in prior studies. We observed that humanities students demonstrated more complex problem-solving approaches, which could be related to the different perspectives identified in the earlier studies.

Our findings uncover several implications for educational engineering practices. First, we support Norris et al.'s suggestion [6] that engineering educators should intentionally provide students opportunities to apply what they have learned about ill-structured problem-solving inside classroom settings. Similarly, as suggested by Amelink et al. [34], these opportunities should include applications of knowledge from within and outside of students' disciplines to allow them to integrate knowledge beyond their disciplinary boundaries.

We are conducting a second round of analysis to uncover a more in-depth and nuanced understanding of students' varying approaches to conceptualizing and solving complex problems. Such an effort will uncover how prior experiences inform the way our participants approached the Lake Urmia scenario and provide suggestions to engineering educators to continue to improve engineering education. Future research could also examine students' problem-solving behaviors in real-life contexts to provide greater insight into students' approaches to complex problems and conduct comparative analysis of curricula and classroom practices to explore how humanities students and engineering students are taught complex problem-solving at the classroom level.

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