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Assessing Student's Stakeholder Awareness Skills in an Introductory Engineering Design Course through Systems Thinking Scenarios

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ABSTRACT

Engineering students need to be trained to deal with complex engineering problems and be capable of developing solutions that meet the needs of stakeholders at different levels, from direct users to regulation entities. Stakeholder awareness is defined as a construct concerning the ability to identify and include relevant stakeholders. A successful engineer should be able to identify various stakeholders, understand their roles, and effectively communicate with them to facilitate the identification and implementation of possible solutions. Therefore, it is important to foster the development of such skills in an introductory engineering design course. The aim of our study reported in this paper is to assess students’ level of stakeholder awareness skills and identify the area(s) of development (gaps). The results provide us with insights to develop effective teaching strategies to address these gaps.

Study participants were tasked to complete a scenario-based assessment proposed by Grohs, et al. [1] that focuses on systems thinking and problem-solving as engineers by responding to a scenario that addressed technical and social contexts. The activity focuses on participants’ responses to a given scenario and the prompts intended to guide respondents in a systems-thinking approach. Data were collected electronically and analyzed using qualitative coding methods by applying the assessment tool rubric to evaluate student responses using systems thinking constructs from the framework. We rated stakeholder awareness according to the rubric which rates a respondent’s ability to identify stakeholders across the group categories and the nature of engagement with the stakeholder.

The results show that most of the participants (approx. 90%) scored high identifying more than one group of stakeholders. However, a lower percentage (35%) of participants talked about collaborative interaction with the different stakeholders and had trouble describing the process of planning a response to the problem.

This study is contributing to laying out the foundation of our overarching project in which we are seeking to develop teaching content that focuses on systems thinking skills by providing a solid understanding of the current systems thinking skill baseline level among university engineering students. Results from this study will also inform the systems thinking community and enrich the literature on human-centered design that discusses how engineering students understand and navigate design problems in complex systems in a design course.

1. INTRODUCTION

Although certain basics of engineering will not change, engineers have to adapt to the explosion of knowledge, the global economy, and the complex systems they work with when entering the workplace. Engineering education needs to, therefore, evolve to reflect these ongoing changes [2]. A report titled “Educating the Engineer for 2020 and beyond” published by the National Academy of Engineering (NAE) [3] has offered several overarching trends, one of them being “… a growing need for interdisciplinary and system-based approaches …”. As technology advances, there is an increasing demand for an interdisciplinary approach to translate operational needs and requirements into a system solution that satisfies customer expectations and meets public acceptability [4].

Such an approach requires engineers to be able to identify various stakeholders, understand their roles, and effectively communicate with them to facilitate the identification and implementation of possible solutions. In the system engineering design process, identifying the right functional and non-functional systems requirements is crucial for the success of the design. Throughout the process, the interaction with various stakeholders plays an essential role in ensuring the design may satisfy the expectations while being delivered on time and within budget. Gibson et al. [5] described a seven-step approach for goal development at the early stage of system analysis, including generalizing the question, developing a descriptive scenario, developing a normative scenario, developing the axiological component, preparing an objectives tree, validation, and iteration. They identified goal development as the "most difficult, unfamiliar, and tension-producing phase in system analysis", and they advocated for high-level involvement from various stakeholder groups in all steps.

A solution in which stakeholders are actively involved in requirements definition and solution implementation has a higher chance of success. Such a view is a central idea for the systems engineering design process and the Human-Centered design process (HCD) [6]. Many popular system engineering design process models, such as the "Vee" model [7] and the spiral model [8], emphasize iterative approaches that involve various stakeholders in the design processes. The HCD approach guides designers to understand and respond to the needs of user(s), reframe problems, and iterate to develop their solutions. HCD also helps designers understand and empathize with who they are designing for, the stakeholders' underlying needs, and test concepts through rapid prototyping [9]. In both processes, stakeholder awareness, defined as a construct concerning the ability to identify and include relevant stakeholders, is a desirable skill for engineers and a necessity for any successful design and solution implementation.

The goal of this study is to assess the stakeholder awareness skills among engineering students in their early years of university education. It aims to highlight the strengths and identify any area of improvement in our current engineering program curriculum that may impact such skill development. With that, we will design and deliver proper educational materials to add to the engineering program curriculum to further enhance stakeholder awareness skills among students in future studies.

The remaining sections of the paper are organized as follows. Section 2 describes the data sources, data structure, and approach we used to analyze students' stakeholder awareness skills. The findings are presented in Section 3, as well as the data analysis. Section 4 includes some discussions and implications, as well as the limitation of this study. Finally, in Section 5, we discuss the future directions of our research.

2. METHODS

We utilized the systems thinking assessment tool, which included a hypothetical problem scenario and rubric developed by Grohs et al. [1] to assess students' skills related to various constructs of systems thinking. We are building on previous phases (I and II) of research evaluating students' understanding of systems thinking constructs in this study (Phase III). In Phase I of our research, we applied the rubric to assess students' skills and identify potential skills or constructs not included in the rubric [10]. Phase I rubric evaluation resulted in scoring guidelines that included the distinction between baseline thinking and the interaction between constructs. In Phase II, we focused on students' responses that evaluated problem identification and found that lack of certain ability among engineering students to properly identify the problem and any information needed to solve the problem when given a problem-based scenario [11]. The results of each phase are to inform future iterations of the systems thinking activity. Students completed the systems thinking activity as an individual course assignment. The course is an introductory engineering course emphasizing engineering design using a design process that incorporates the end user and other stakeholders. The course focuses on learning and applying the human-centered design process in engineering contexts. Students are introduced to the human-centered design process, and then learn and apply specific engineering skills including solid modeling, 3D printing, building with hand and power tools, Arduino electronics, and basic programming. One major deliverable is a final design project, where students work in teams to develop a design solution that meets the needs of a specified user group and associated stakeholders.

At the time of the data collection for this study, all students enrolled in the course completed the activity. Students had the option to participate in the study or choose not to have their responses included in the study, and all data collection protocols followed IRB at the home institution of the authors. We collected data in the Fall 2020 semester and 23 students agreed to participate in the study. Academic class standing reported by participants was 100% freshmen, 0% sophomore, 0% junior, and 0% seniors. The participants also represented a variety of engineering disciplines/ majors (23% Mechanical Engineering, 13% Electrical Engineering, 4.5% Aerospace, 18% Civil or Coastal Engineering, 4.5% Environmental, 4.5% Computer Science, 23% Undeclared, 9.5% Other/ non-engineering). Gender identification (women, men, non-binary) identified by the participants was 36% women, 64% men, and 0% non-binary.

Our goal in this study was to evaluate students' stakeholder awareness associated with the problem scenario, including stakeholder identification and involvement. The research team applied the rubric presented by Grohs et al. [1] to evaluate participants' responses to prompts 3 and 4 that map to stakeholder awareness.

2.1 Systems Thinking Assessment Tool

The problem scenario and rubric [1] were developed to measure systems thinking competencies in contexts beyond self-reported attitudes and behaviors. The problem scenario is a hypothetical vignette that asks students to consider multiple details in an ill-structured problem context. The scenario provides information that possibly represents engineering and technical skills, economic feasibility, ethical considerations, and cultural sensitivity, which can be considered when studying potential solutions [1].

> "The Village of Yakutia has about 50,000 people. Its harsh winters and remote location make heating a living space very expensive. The rising price of fossil fuels has been reflected in the heating expenses of Yakutia residents. In fact, many residents are unable to afford heat for the entire winter (5 months). A Northeastern Federal University study shows that 38% of village residents have gone without heat for at least 30 winter days in the last 24 months. Last year, 27 Yakutia deaths were attributed to unheated homes. Most died from hypothermia/exposure (21), and the remainder died in fires or from carbon monoxide poisoning that resulted from improper use of alternative heat sources (e.g., burning trash in an unventilated space)."

In this study, the researchers changed the name of the hypothetical village, "Abeesee" to "Yakutia" to reflect a more realistic context. The text provided to students for the activity is, "*The region described in the scenario is real and its community members experience very harsh winters, however the specific details of the scenario are fictional for the purposes of this assignment.*" We applied the assessment tool rubric to evaluate the student responses sample using systems thinking constructs from the framework. The framework has three dimensions to be considered: the problem dimension, perspective, and time. The interaction of associated constructs within each dimension provided a way to analyze students' perspectives and competencies when taking multiple interactive constructs into account [1].

This study analyzes what participants answered when asked to identify relevant stakeholders, which we refer to as stakeholder identification (prompt 3), and how they would describe the process to plan a response to the problem, which we refer to as stakeholder involvement (prompt 4). Below are these two prompts given to the participants:

Prompt 3: *What groups or stakeholders would you involve in planning a response to the problems/issues in Yakutia?*
Prompt 4: *Please briefly describe the process you would use to plan a response to the problems/issues in Yakutia.*

Figure 1 shows the rubrics provided by Grohs et al. [1] in their original study and this same one was used for grading participants on these two prompts in this study. Since level 2 shows sublevels, we used 2.1 and 2.2:

Construct	Criteria and Rating Guide	Rating
Stakeholder Awareness *Prompts 3 and 4*	**0** No response was provided, or respondent only provided a list of stakeholders but no discussion on the role that the stakeholders will play in identifying and implementing possible solutions **1** The response includes a list of stakeholders; discussion of role of stakeholders is limited only to ***one group of stakeholders*** (community, or power/politics, or experts) providing ***input*** in discussions to identify possible solutions **2** The response lists an array of various stakeholders (community, power/politics, experts). Discussion of the role of stakeholders includes: 1. ***one group of stakeholders*** being ***engaged*** in activities to identify and implement possible solutions; or 2. ***more than one group of stakeholders*** providing ***input*** in discussions to identify possible solutions **3** The response lists an array of various stakeholders (community, power/politics, experts). Discussion of the role of stakeholders includes all stakeholders ***iteratively giving input and engaging with each other*** to identify and implement possible solutions. The discussion explicitly includes listening to the community voice and getting buy-in from the community	

Figure 1 - Rubrics provided by Grohs et al. [1] to evaluate participants' answers for prompts 3 and 4.

3. RESULTS

3.1 Data Analysis

Using the previously identified systems thinking assessment tool, each participant's answer was rated by the three raters (authors) independently. A shared file was created in which each of the raters input their score for each of the participants individually. The grades were then compiled and analyzed. An example of the grading file for prompt 3 is shown in Table 1 for participant ID FA20-9:

	Prompt 3: Stakeholder Identification					
	Rater	***Notes by rater 1***	***Rater***	***Notes by rater 2***	***Rater***	***Notes by rater 3***
Student ID #	Rater 1		Rater 2		Rater 3	
FA20-9	3	mentions villagers and other stakeholders to work together	2.2	Stakeholders referenced; suggest engaging industry and the government, I.e., stakeholders, to contribute to solutions	2.2	list of stakeholders, including the government.

Table 1 - Rating of participants' answers for participant FA20-9 for Prompt 3

Similarly, the rating for prompt 4 for the same participant is shown below in Table 2 as an example.

	Prompt 4: Stakeholder Involvement					
	Rater	***Notes by rater 1***	***Rater***	*Notes by rater 2*	***Rater***	***Notes by rater 3***
Student ID #	Rater 1		Rater 2		Rater 3	

FA20-9	2.1	discussion only includes one group of stakeholders	2.1	The response focuses on a solution/ approach; mentions one stakeholder group	2.2	Present the list of stakeholders providing input to the participant, but no interaction between stakeholders is mentioned

Table 2 - Rating of participants' answers for participant FA20-9 for Prompt 4.

For determining the level of agreement between the three raters when scoring each participant's, we applied the Weighted Fleiss' Kappa method [12]–[14] which can be used to show that more than two raters provided ratings that were not random and quantifies the "relative seriousness of each possible disagreement" [13, p. 608]. Weighted Kappa values greater than 0.75 represent "excellent agreement beyond chance," and values of 0.40 or lower represent "poor agreement beyond chance" [13, p. 608] Therefore, scores higher than 0.4 and lower or equals to 0.75 represent fair agreement. Such analysis for the two prompts reported in this paper resulted in a score of 0.48 for prompt 3, and 0.41 for prompt 4. Both scores, therefore, represent a fair agreement beyond chance among the raters [13]. In detail, for prompt 3, the raters had a full agreement in 13 out of 23 (56.5%) participant's answers, and there was no full disagreement among the raters in any answers (i.e., at least two raters gave the same score to any participant). Likewise, for prompt 4, there was full agreement among the raters in 9 out of 23 (39%) participants' answers, and there was no full disagreement among the raters for any answers.On the other hand, when there was disagreement in one of the raters, the participant's level of response was determinedby selecting the student's level in which the other two raters agree. For example, for participant FA20-4, the three raters give them a score of 1, so that was the score that was reported. Similarly, for participant FA20-5 the reported score was 3 because two of the raters score the answer in level 3 and one in level 2.2. All participants' final scores for these two prompts are reported in the next sub-section.

3.2 Findings

Prompt 3: Eight participants' answers (35%) were scored in the highest response quality level (level 3), 13 (56%) were scored in the previous level 2.2, and 2 participants' answers (9%) were scored in level 1. The distribution of participants' answers for Stakeholder Identification (the number of participants, the percentage of participants) is shown in Figure 2.

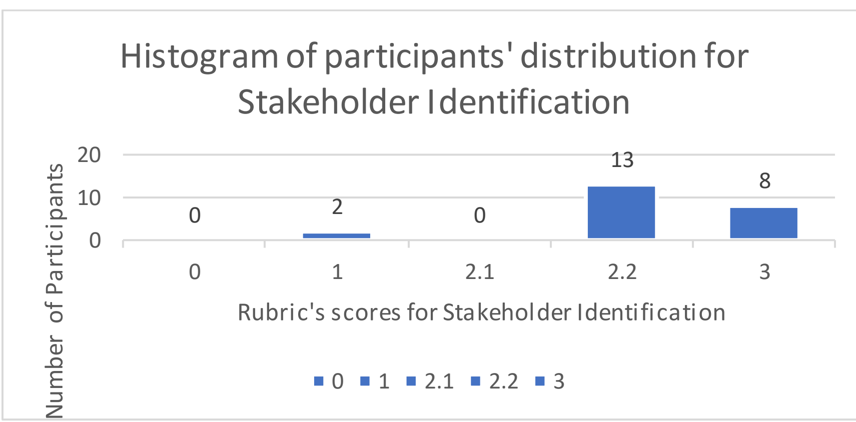

Figure 2 - Distribution of participants' answers to prompt 3: Stakeholder Identification

Prompt 4: Six participants' answers (22.2%) were scored in the highest response quality level (level 3). Five (21.7%) were scored on the previous level 2.2. 6 answers (22.2%) were scored on level 2.1, and 5

(21.7%) were scored on level 1. One answer was scored on level 0 (4.3%). No answer was scored as irrelevant. The distribution of participants' answers for Stakeholder Involvement (the number of participants, the percentage of participants) can be seen in Figure 3.

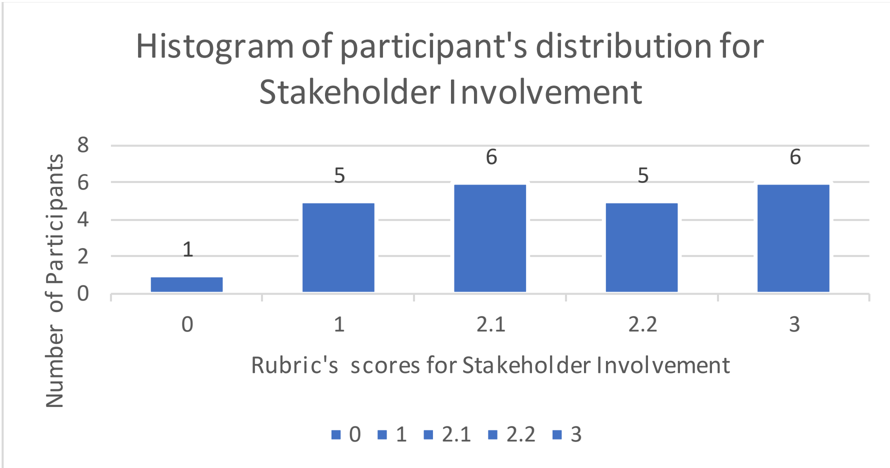

Figure 3 - Distribution of Participant answers for prompt 4: Stakeholder Involvement

4. DISCUSSION AND IMPLICATIONS

Our study's findings show that over 90% (35% scored 3 points while 56% scored 2.2 points) of student participants can identify multiple stakeholders when prompted with a specific question to identify stakeholders (prompt 3). Fewer of them can consider stakeholders as an integral part of the solution development process when this aspect is not emphasized in the question (prompt 4). Fifty percent of the participants discussed getting input from more than one stakeholder, and only 27% went beyond and made them part of the team seeking to find a solution to the problem.

Stakeholder awareness has been a relevant topic in engineering education, especially in systems and engineering design-related literature. The rubric stated that an "ideal response," represented by a score of 3 in the rubric [1, p.115] on prompts 3 and 4 is one in which the participant would identify several stakeholders and engage/collaborate/work with them to develop a solution. The results from our study show that engineering students can identify stakeholders in a problem setting but struggle to develop processes to involve and work with them when addressing an open-ended problem. Complexity is a challenge when addressing any problem in a system. Such complexity is due to the interwoven relationships and interactions among different entities of the system. Stakeholders' involvement is crucial in the attempt of managing complexity and solving the problem [15]. We evaluated students' responses to demonstrate their ability to identify and understand relevant stakeholders and their role.

Our findings are aligned with Zoltowski et al.'s study [16] in which one of the ways students experience human-centered design is by seeing the user as 'an information source,' while others discuss higher understanding and stakeholder involvement. This study shows that although most of the participants came up with a list of several stakeholders, most of them still saw them more as information sources (approximately 74% of students were below level 3) than as key participants who are "iteratively giving input to each other" [1, p. 119]. Lacking the ability to see stakeholder groups beyond input sources shows an opportunity for engineering programs, especially systems engineering programs, to nurture in their students the knowledge, skills, and tools that could help them better understand and involve stakeholders in the problem-solution related stages. Literature describing course designs for such training exists, for example using a case study on past technology adoption and environmental injustices related to stormwater management plans as a learning module that allows educators to bring stakeholder concerns into the classroom. [17] An example for capstone design is proposed by [18], which included students working with real stake holders throughout the design processes and required them to attend meetings with community stakeholders and educate the public about the benefits of the proposed designs. Still, the literature in this area is still scarce, which might mean that additional support from Engineering Colleges and Department's chairs is needed to support faculty in this endeavor. We believe our work is beneficial for those leaders who need evidence of the need to move resources in the direction of creating such opportunities to students, and to the educational practitioner aiming to understand how they can use the rubric developed by Grohs et al, and create strategies to develop students' stakeholder awareness. Such preparation would enable students to reach a higher impact in their capstone design projects, and they might be better prepared to establish more "useful" [19] interactions with their stakeholders.

4.1 Limitations

The findings from this study are limited by the number of participants in our sample and that is why generalizations cannot be made at this time. However, it is our intention to continue our study with a larger group of participants to gain more insights. Another limitation is that students were working in a fictional scenario given in an academic setting in this study. Engaging with stakeholders in a real-world environment can affect participants' perceptions of who are the stakeholders and how to engage various stakeholders. Stakeholder identification and engagement from the student's perspective may be different if they were to engage in a real, interactive scenario, compared to the perceptions they expressed in the written scenario exercise. With that, it may be beneficial to design teaching materials/modules which may offer more interactive exercises for the students to be engaged with various stakeholders in future research. This study provides us with preliminary results to help us understand students' current skill level of stakeholder awareness when tasked to provide a written solution to a given problem.

5. FUTURE DIRECTIONS FOR RESEARCH

This study is contributing to laying out the foundation of our overarching project in which we are seeking to develop teaching content that focuses on systems thinking skills by providing a solid understanding of the current systems thinking skill baseline level among university engineering students. Investigating ways in which students can learn about stakeholders and get higher awareness of them will be one of the goals in our curriculum development endeavor. Results from this study will also inform the systems thinking community and enrich the literature on human-centered design that discusses how engineering students understand and navigate design problems in complex systems in a design course. Some of the future directions we foresee for this study in addition to the curriculum development idea is to use the assessment tool with students in capstone design projects and compare the outcomes with those of students in their first year to see how engineering programs and which program activities or students' experiences have contributed to the development of students' stakeholder awareness. For example, it will be worth studying the impact of internships and/or extracurricular activities on such stakeholder awareness. In the same way, using the rubric for assessing its effectiveness when assessing students' systems thinking while addressing different scenarios or design projects, such as capstone design projects.

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