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A Pilot Study Assessing Student's Problem and Information Identification Skills in an Introductory Engineering Design Course

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Introduction

As systems continuously grow in size and complexity, systems thinking is becoming increasingly crucial for today's engineers [1], [2]. Engineering graduates should be able to handle complex engineering systems and problems. Their design solutions must meet the needs of stakeholders at different levels, from direct users to regulatory entities. To achieve these goals, educating engineering students in systems thinking, which can facilitate such goals, is crucial to the students' success and requires a teaching and learning approach that is supported by a socio-technical context-rich environment. Instead of offering a problem statement with pre-defined knowledge, educators should begin with presenting an engineering problem to students, training them on how to obtain and extract proper information to identify the true problem themselves. Students will need to discover different parameters and measurements of the system, explore important and relevant elements and entities using a holistic approach before they begin to develop a systems architecture [3], [4]. Identifying the problem as well as the information needed is the foundation to any system architecting and solution proposing when facing any real-world problem. Success in this initial step also suggests competence and builds confidence. Such skills, as parts of systems thinking skills, can be learned from experiences, and/or from a formal teaching and learning framework that emphasizes hands-on practices [5].

However, to our best knowledge, there is no existing curriculum that focuses on developing systems thinking skills among engineering students [5]. This recognition of the inadequacy of current educational methods in helping engineering students learn systems thinking skills is a focal point of this research. The overarching goal is to create learning content modules that can be implemented to develop and assess systems thinking skills, including problem and information identification skills. To better understand the students' current level of such skill is naturally the first step of this process. In our previous study [6], we have assessed students' systems thinking using a scenario-based assessment and accompanying rubric [7]. Furthermore, we evaluated this assessment tool for establishing the engineering students' current systems thinking skills (baseline), as well as identifying any potential areas of improvement. We have concluded that the assessment tool is sufficient for those purposes. Therefore, in this study, we continue to use this scenario-based assessment tool to properly assess students' systems thinking skills, more particular, their ability for the problem and information identification when confronted with a problem.

Systems Thinking and Its Current Assessment in Engineering Education

Systems thinking is a set of tools for observing the interrelations among system components and the underlying complex relationships [8], [9]. Systems Thinking in engineering may be used in several different ways: to gain an understanding of a complex situation, to gain sufficient understanding to make predictions of future system behavior, to solve a problem, or to create a new or modified system [10].

Educating Engineers in systems thinking requires an approach that begins with the problem and information identification. Students ought to gather sufficient and proper information to evaluate technical and social relationships within the systems and utilize this information to successfully identify the problem with engineering and non-engineering perspectives (such as economic, social, organizational, and others, etc.).

There is no agreement among researchers on what assessment tool can effectively assess systems thinking. Some have developed approaches in which previous knowledge or instruction in systems thinking is not required for participants to engage in the assessment task (e.g. [11], [12], and [7]); while others provide instruction to students that allows them to perform the task before being assessed (e.g. [13]). Furthermore, the literature also shows differences in assessment contexts. Some focus on concepts related to systems dynamics [11], mental models [14], non-linear causal structures in complex systems [15], or the creation of complex causal networks [16]; while others ask participants to address an ill-defined problem that involves societal issues with specific rubric developed (e.g. [7], [17], and [13]).

In this study, we utilized an assessment tool that does not require participants to be previously trained in systems thinking to establish a baseline of systems thinking evaluation among engineering students. This tool includes dimensions to assess the ability of problem and information identification when presented to an ill-defined problem.

The paper is organized as follows: in the Methods section, we introduce the assessment tool, course setting, participants, data collection, and analysis in greater detail. We then present and discuss our results in the Findings section. Finally, the Conclusions section provides some general conclusions, as well as some directions for future work.

Methods

Our primary goal with the overarching effort is to develop a systematic study and evaluation of systems thinking scenarios or learning content that can be utilized in the engineering curricula. Curriculum design theory discusses the crucial role of developing an assessment that is capable of proposing where students are in the developmental trajectory of the object of learning (what needs to be learned) [18]–[20]. Accordingly, we aimed to use systems thinking activity that made it possible to capture student perspectives and provide a method of evaluation for researchers and educators; in that way, we will know where the students are in the systems thinking developmental trajectory, and it will allow us to design effective instructional interventions that move them forward in this trajectory. For the first phase of our research, we utilized the systems thinking assessment tool from a peer-reviewed paper [7] to help identify the areas of improvement in students' current systems thinking skills. Furthermore, we evaluated the rubric (rubric constructs and scoring can be found in Appendix 1) provided in this tool for our application and suggested some modifications to better differentiate the (lack of) skills from the students' responses. With the Institutional Review Boards' (IRB) approval, study participants completed an activity that focuses on systems thinking and problem-solving as engineers by responding to a scenario that addressed technical and social components. Data were collected electronically, and we scored the responses by conducting content analyses. The research team applied the rubric proposed by Grohs et al. [7] to identify the strengths and weaknesses of the assessment tool when using it in the engineering design course.

Context

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. Students engage with end-users and apply a human-centered process to build functional prototypes of their designs as part of the course. The course covers solid modeling, introductory programming, engineering sensors and actuators, data acquisition, and 3D printing for engineering prototyping. It is open to all engineering majors, including undecided engineering majors. There were no pre-requisite or co-requisite course requirements to participate, and most students take the course as an engineering course in their first year to introduce engineering topics in addition to their general math and science studies.

Participants

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. A questionnaire was given to all students to collect demographic information. The response rate for the questionnaire was 98% and 55% of students agreed to participate. The demographic breakdown is as follows: 100% freshmen, 0% sophomore, 0% junior and 0% seniors. All students were of different disciplines (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). Participants answered a gender identification (women, men, non-binary) question and the breakdowns are as follows: 36% women, 64% men, and 0% non-binary. For this study, our focus was primarily on their identification of systems thinking concepts and their application. Future work will explore demographic connections to their responses. No monetary incentives were provided to students although all students were provided 2.5 attendance points, independent of whether they completed the questionnaire or not. All protocols followed IRB at the home institution of the authors.

Systems Thinking Assessment Tool

The activity focuses on students' responses to a given scenario, and the prompts provided in the activity are intended to guide respondents in a systems-thinking approach. The problem scenario and rubric [7] 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-structure 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 [7].

> "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 North Eastern 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 [7].

Data Analysis

Using the Systems Thinking Assessment Tool, each participant’s answer was rated by the three authors independently. We created a shared file in which each of the raters input their score for each of the participants. An example of the table showing the scores for participant FA20-1 is shown in **Error! Reference source not found.**.

Prompt 1: Problem Identification						
	Rater	***Notes by rater 1***	***Rater***	***Notes by rater 2***	***Rater***	***Notes by rater 3***

Student ID #	Rater 1		Rater 2		Rater 3	
FA20-1	2.2	Contextual: economic (cost of fossil fuels), social(safety), and interactions between economic and social.	2.2	cost of fossil fuels and interaction ("deaths due to hypothermia" and "unsafe heating alternatives"	2.2	Expresses a relationship between the cost and the deaths

Table 1 – An example of the table for rating the participants' answers

For determining the level of agreement between the three raters when scoring each participant's answer to determine their response quality, we used the Fleiss' Kappa method [21]–[23] which can be used for more than two raters. Such analysis for the two questions reported in this paper resulted in a score of 0.497 for Problem Identification, and 0.729 for Information Needs. The former represents a fair agreement among the raters beyond chance, while the latter is an excellent agreement beyond chance between raters [22]. For analyzing the participant's distribution on each of the prompts, we determined each participant's level of response quality for each of the questions by selecting the student's level that has the highest strength of agreement between the raters. For example, for participant FA20-1, the three raters give them a score of 2.2. In this case, this participant selected level was 2.2. On the other hand, for participant FA20-4, two of the raters gave score their answers on level 1, while the other gave this participant a score for a level 2.1. In this case, the participant response quality was reported as level 1 because 2 of the raters (66%) agreed on the level. For the Problem Identification question, 12 out of 23 (52%) of the participants' answers had full agreements among raters, and there was no full disagreement among the raters in any answers. Regarding the Information Needs question, there was full agreement among the raters in 17 out of 23 (74%) participants' answers, and there was no full disagreement in any answers.

Findings

Problem Identification: 5 participants' answers (22%) were scored in the highest response quality level (level 3). 11 (48%) were scored in the previous level 2.2, 2 participants' answers (9%) were scored in 2.1 level, and 4 participants' answers (17%) scored in level 1. One of the answers was scored as irrelevant (and was given a level 0 score). The visualization of the distribution of participants' answers for Problem Identification is shown in Figure 1- Distribution of participants' answers for the Problem Identification question.

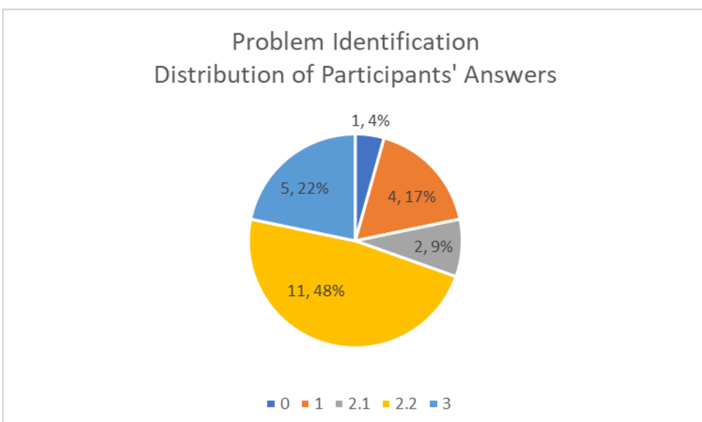

Figure 1- Distribution of participants' answers for the Problem Identification question

According to the rubric, it is key to identify that a problem has technical and contextual aspects and that elements from these aspects interact in a way that makes them complex. Less than a quarter of the participants' answers (22%) have the constructs of an ideal response which indicates that this group of engineering students when addressing open-ended problems within a complex system are lacking in their ability to see that the problem has more than one dimension (either contextual or technical) that needs to be considered for providing an effective solution. Still, they saw interaction within the elements they identified in that dimension. Likewise, 30% of them showed a lack of ability to perceive the interaction between the different problem components.

Information Needs Identification: 2 participants' answers (9%) were scored in the highest response quality level (level 3). 3 (13%) were scored on the previous level 2.2. 11 answers (48%) were scored on level 2.1, and 7 (30%) were scored on level 1. No answer was scored as irrelevant. A visualization of the distribution of participants' answers can be seen in Figure 2.

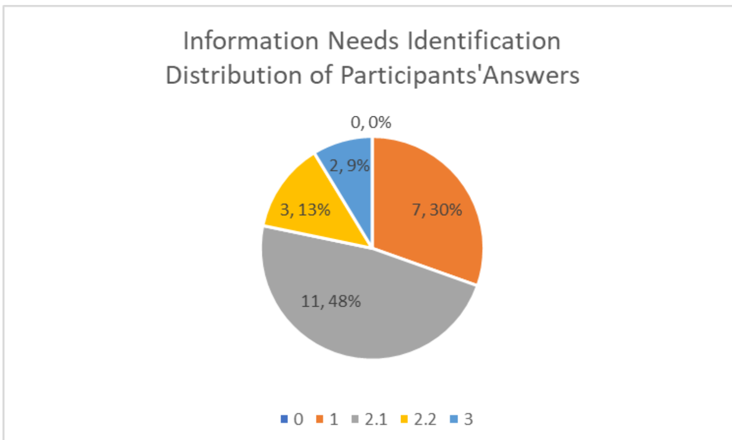

Figure 2 - Distribution of Participant answers for the Information Needs Identification question

The rubric states that a high-quality answer includes the need for information related to both technical and contextual aspects, and there is an integration or connection mentioned. 9% of the participants' answers had elements that are a high-quality response (level 3), and just 13% of the answers mentioned at least the need for information either in contextual aspects, or technical aspects that are integrated within elements of the identified dimension. The rest of 78% of the participants lacked seeing or acknowledging information integration.

In systems thinking, complexity is a key concept, and such complexity is created due to the interactions among the different components of the system. Lacking to recognize such interactions shows the need for a curriculum that tackles as learning goal students' identification of such interactions.

Conclusions

The study presented in this work aimed to assess the problem and information identification skills, which is a subset of the systems thinking skills, among current engineering students, who have not yet received any formal training of systems thinking skills in their university education. The findings provide evidence that there is a 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. These findings may serve as motivations to further assess other system thinking skills among engineering students and to consider developing teaching materials that emphasize the importance of problem and information identification skills and provide sufficient training for them.

In the future, we plan to collect and analyze additional student responses from the introductory design course and other courses from various engineering disciplines to assess students' current systems thinking skills in various contexts. Future analysis will also investigate possible relationships between participants' demographic data and their responses to the question prompts. These findings may help provide the foundation for the assessment we need to develop aligned curriculums that intend to develop systems thinking skills among engineering students. By providing a solid understanding of the current systems thinking skill baseline level, we will know better what students need to learn, so we can design instructional interventions that either reinforce what they already know or move them forward. Ultimately, with these instructional interventions being implemented into engineering curricula, we can provide an educational path to improve engineering students' systems thinking skills.

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Appendix 1 – Rubrics for the scenario developed by Grohs et al. [7]

Below you will find the rubrics developed by Grohs et al. that we tested for this study (problem identification and information needs). The full instrument developed by Grohs et al. includes the vignette, all the prompts in the different phases (processing, response, and critique phases), the mapping of constructs to prompts, and the definition of terms. You can find it in the Appendices A, B, C, and D of their paper.

Table B1
Rubric – Operationalizing Systems Thinking: Problem Identification.

Construct	Criteria and Rating Guide	Rating
Problem Identification *Prompt 1*	**0** No response was provided or respondent was unable to identify a relevant problem **1** The problem statement identified is ***only technical*** or ***only contextual*** (economic, political, environmental, social, time, etc) in scope **2** The problem statement a) dentified both ***technical*** and ***contextual aspects*** but did not acknowledge ***interaction*** and complexity between issues b) identified ***technical aspect*** or ***contextual aspect only***, and acknowledges ***interactions*** and complexities between issues **3** The problem statement identified both ***technical*** and ***contextual aspects*** and acknowledges ***interactions*** and complexity between issues	

Table B2
Rubric – Operationalizing Systems Thinking: Information Needs.

Construct	Criteria and Rating Guide	Rating
Information Needs *Prompt 2*	**0** No response was provided, or respondent sought information that was not relevant to the scenario **1** The response identified information needs focused only on one ***aspect:*** either ***technical*** only or ***contextual*** (economic, political, environmental, social, time, etc) only **2** The response 1. identified several relevant information needs addressing both ***technical*** and ***contextual aspects***, but these ***aspects*** are not specifically ***integrated*** 2. identified several relevant information needs addressing ***technical aspect*** or ***contextual aspect only***, and there is acknowledgment of ***integration*** within information needs of the ***aspect in focus*** **3** The response identified several relevant information needs that address both ***technical*** and ***contextual aspects*** and ***integrates*** these ***aspects***	