Board 110: Defining and Assessing Systems Thinking in Diverse Engineering Populations

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Defining and Assessing Systems Thinking in Diverse Engineering Populations

Engineers are called to play an important role in addressing the complex problems of our global society, such as climate change and health care. In order to adequately address these complex problems, engineers must be able to identify and incorporate into their decision making relevant aspects of systems in which their work is contextualized, a skill often referred to as systems thinking [1] - [3].Within engineering, research on systems thinking tends to emphasize the ability to recognize potentially relevant constituent elements and parts of an engineering problem (e.g., [4] – [6]) rather than how these constituent elements and parts are embedded in broader economic, sociocultural, and temporal contexts as part of a larger system, and how all of these must inform decision making about problems and solutions. Although several studies in engineering outside of the systems thinking literature focus on the ability to identify contextual elements of problems (e.g., [7], [8]), a core engineering competency emphasized in the ABET [9] criteria, contextual awareness is largely overlooked in existing definitions of systems thinking. Thus, empirical investigations have not yet considered how awareness and recognition of the elements of a comprehensive definition of systems thinking, inclusive of the constituent parts of a problem and the larger sociocultural and temporal context, inform problem solving.

A lack of recognition of some elements of systems thinking, such as an awareness of a particular sociocultural context or the coordination of work among members of a cross-disciplinary team as core engineering skills [10], [11] stands to alienate those whose strengths and passions are related to, for example, engineering systems that consider and impact social change. Studies show that women and minorities, groups underrepresented within engineering, are drawn to engineering in part for its potential to address important social issues [12] – [14]. Emphasizing the importance of systems thinking and developing a more comprehensive definition of systems thinking that includes both constituent parts and contextual elements of a system can help students recognize the relevance and value of these other elements of engineering work and support full participation in engineering by a diverse group of students.

Our study focused on an expanded definition of systems thinking that includes awareness and consideration of sociocultural contexts. The complexity of today's grand challenges requires we correct these misconceptions of engineering work and invite more diverse others to use their talents to address these challenges. Through our work, we hope to better characterize what comprehensive systems thinking expertise looks like across a number of engineering fields and contexts and better understand the varied personal, academic, and professional experiences that may be related to individuals' awareness of or aptitude for various elements of systems thinking. Specifically, we seek to address two key questions:

> RQ 1: How do engineers of different levels of education and experience approach problems that require systems thinking?
>
> RQ 2: How do different types of life, educational, and work experiences relate to individuals' demonstrated level of expertise in solving systems thinking problems?

Additionally, we hope to draw on our empirical data characterizing the ways engineers differently approach comprehensive systems thinking across a range of expertise to develop a scenario-based assessment tool that educators and researchers can use to evaluate engineering students' systems thinking competence.

Defining Systems Thinking

Consistent with the aforementioned need to define and study systems thinking in a comprehensive, inclusive manner, our definition of systems thinking is a holistic approach to problem solving in which linkages and interactions of the immediate work with constituent parts, the larger sociocultural context, and potential impacts over time are identified and incorporated into decision making. This working definition of systems thinking used in our research builds upon the work of researchers who have characterized different elements of systems thinking, including a consideration of the relationship between various components of a product or process, of stakeholder needs, of the social and environmental context, and of temporal dimensions [4] - [6], [15] - [17]. Our definition of systems thinking is represented in Figure 1, where the "component" of a problem that an individual may be working on is in the center. The expanding circles represent the contexts that can and should be considered in making decisions about the solution(s) and their appropriateness. Many times, this component is part of a larger technical system, thus other pieces or components within the system both must be considered and can have an impact on the success of the solution. This technical system exists within another existing structure, such as infrastructure of the environment or regulations in a particular field of work. Stakeholders include users as well as others that have influence or will be influenced by the problem and solution developed. These aspects all exist within a larger sociocultural and environmental context as well as within a timeline of what has been done before and the expected future.

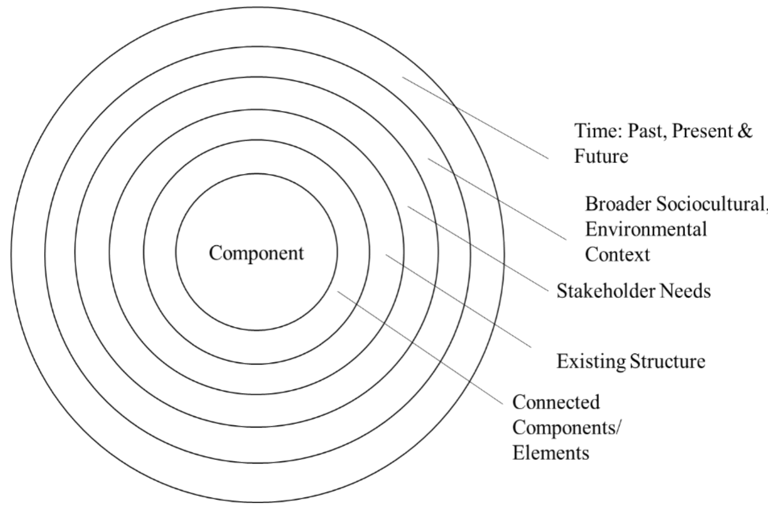

Figure 1: Elements of Systems Thinking

Study Design

Our study is comprised of three phases. The first two phases include semi-structured interviews with engineering students and professionals about their experiences solving a problem requiring systems thinking and a think-aloud interview in which participants are asked to talk through how they would approach a given engineering scenario and later reflect on the experiences that inform their thinking. Data from these two phases will be used to develop a written assessment tool, which we will test by administering the written instrument to undergraduate and graduate engineering students in our third study phase.

In the first phase of our study we seek to characterize different levels of systems thinking expertise. We are conducting interviews with engineering students and practitioners to understand individuals' concrete experiences with systems thinking (RQ1), the approaches they have used to solve complex engineering problems, including how they think about causality (RQ1), and the relationship of their prior life, educational, and work experiences with their systems thinking practice and skill (RQ2). The interviews are designed to collect rich data about the experiences of a relatively small, but diverse, group of engineering students and professionals. We ask participants to walk us through instances where they have relied on systems thinking in their own work, which we expect will contribute to our understanding of systems thinking in an applied, realistic context. We also ask interviewees to discuss life experience that they believe have contributed to their approaches to complex problem solving. This phase serves as a foundation on which to base subsequent phases of data collection, as we will begin to understand differences in what individuals attend to in exploring solutions to a problem that requires systems thinking.

In the second phase, we will conduct think-aloud interviews in which we present participants with an open-ended engineering problem scenario and ask them to discuss how they would explore a possible solution, walking us through their thought process for each decision they make, paying particular attention to the connections individuals make between different elements within the problem and solution spaces. This phase allows us to compare the particular strategies individuals with different levels of systems thinking skill employ as they are solving a problem and gain an in-depth understanding of their rationale for decision making (RQ1) and how, if at all, the complexity of individuals' causal reasoning relate to their demonstrated systems thinking expertise. It will also help us refine our initial understanding of different levels of systems thinking ability and provide the foundation for our empirically grounded systems thinking assessment tool. By using a common scenario, we will be able to focus in greater detail of differences in how engineers with different types of experiences approach a problem, and compare the elements and relationships to which individuals attend.

Phase 3 will build on our findings in Phases 1 and 2. Using the empirically grounded classification of the problem solving approaches associated with different levels of systems thinking ability (Phases 1 and 2), we will build a scenario-based systems thinking assessment tool for use in Phase 3. In this phase, we will test assessment tool and its ability to distinguish between levels of systems thinking expertise (RQ1) and learn more about educational and life experiences that may be associated with differences in students' systems thinking ability (RQ2).

Preliminary Findings

At the present time, we have completed our first phase interviews with undergraduate engineering students and are in the process of collecting and analyzing data with more experienced engineering graduate students and professionals. Preliminary findings from these interviews with undergraduate participants suggest some tentative patterns about the ways relatively inexperienced engineers utilize systems thinking to solve complex problems. In particular, early analysis offers some insight into the major factors students identified as key in their complex problem solving. The majority of students focused primarily or exclusively on those factors relating to the technical details of a particular project component or part, the technical or mechanical details of the larger product being created, and the immediate existing structure surrounding the project – including course requirements or team competition rules. A number of students also mentioned considerations relating to the temporal elements of a problem. For many, this meant an emphasis on the project timeline or time as a factor that restricted them from exploring other solutions. Several students mentioned looking at how similar projects had been addressed previously or how they might adapt their solution in the future.

Other types of factors were less commonly mentioned among undergraduate engineers. Several students mentioned factors relating to the team tasked with collectively addressing the problem. Of these, the majority of students described the training and capabilities of team members as potential constraints to consider when assessing the feasibility of a given solution. However, several students mentioned interpersonal team dynamics, shared goals, communication, and team values as additional factors they considered. Very few students identified stakeholder needs or perspectives as something they considered and only one student mentioned accounting for the sociocultural context as a factor in their design without prompting. Interestingly, the students who most heavily emphasized stakeholder perspectives and contextual or cultural factors as things they accounted for in their solutions expressed that their personal emphasis on these factors was in contrast to the majority of their engineering peers. One participant explained that, while she views her emphasis on navigating interpersonal, cultural, and emotional considerations as a strength, it "might not make her as strong technically." This perceived tension between the technical and contextual or social considerations of engineering work was also emphasized by participants in focus groups that we used to pilot different problem scenarios for the second phase of our study, and is a theme we intend to explore further in our analyses.

Next Steps

Ongoing and future work on the project includes completing data collection with experienced engineering practitioners about their experiences solving a complex problem. Additionally, we are beginning analysis of the qualitative interview data from the Phase 1 interviews. A primary focus of this analysis includes the different approaches and priorities of different engineers in solving complex problems and the ways these experiences relate to or are informed by their past experiences. Next, we will begin the scenario-based follow up interviews with a subset of participants in Spring 2019. Findings from Phase 1 and Phase 2 interviews will be used to develop a classification scheme of markers of novice, intermediate, and expert systems thinking. We will then develop and test a scenario-based written assessment that will enable us to identify participants' levels of comprehensive systems thinking expertise based on the empirically-derived classification scheme. We will test this scenario-based assessment in administrations with undergraduate and graduate students in engineering at several universities and use this data to finalize our assessment tool.

Given the importance of systems thinking in engineering education and practice [1] - [3], it is our belief that a typology representing key differences in strategies across the novice-expert continuum and a tool to assess individuals' systems thinking skill represent much-needed products with relevance to a number of engineering contexts. A systems thinking assessment tool would allow instructors to consistently measure students' systems thinking skill and potentially measure systems thinking skill development after engaging in a particular educational intervention in which systems thinking is a desired outcome. Further, it is our hope that an assessment tool that is inclusive of often-overlooked elements of systems thinking such as interpersonal, contextual, and temporal contexts helps to reaffirm the importance of these elements for successfully addressing complex engineering problems.

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