Developing a tool for the assessment of systems thinking in K-12 settings

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***Abstract*— Systems thinking is a skill that enables students to grapple with complex problems, often to which there is no clear problem definition or solution, there are many stakeholders, and there are many systems involved (e.g. sociotechnical or socioecological systems). Fostering the development of systems thinking skills is crucial as the problems students encounter in their lives, and in formal and informal educational settings, are increasingly complex. Ongoing research points to the need for more domain-general tools to assess systems thinking in a variety of K-12 settings. Many existing tools or methods used to assess systems thinking in K-12 are often domain specific (e.g. the water cycle in environmental science) and do not always transfer well to more complex problems across content areas. Furthermore, grounding the development of systems thinking skills in the locally relevant contexts that inform and affect students' day-to-day lives also offers the opportunity for students to engage in problems they find interesting and in which they may connect more deeply. This work-in-progress paper presents the development of a general tool informed by existing research in systems thinking and pedagogical practices in K-12 settings. The initial tool development is based on an existing published tool that has been used in undergraduate settings that challenges students to consider an ill-structured problem based on a real world scenario, in which a rubric was defined and applied to measure different systems thinking competencies. The existing tool measures students' ability to identify various contextual and technical aspects of a problem, to identify various stakeholders and stakeholder needs, and to identify short-term goals, long-term goals, and unintended consequences of potential solutions. Knowledge and experience from the development of this tool will be used to pilot an assessment with K-12 students to measure their systems thinking skills in problems that are relevant to them and their experiences.**

Keywords*— *systems thinking, K-12, assessment

I. Introduction

Systems thinking is a critical competency many students need to develop to understand and deal with the complexity of many problems facing society. Many of these problems are ill-structured with no clear solution and often involve many stakeholders, perspectives, and problem dimensions, and may involve many systems, such as sociotechnical or socioecological problems, for example. However, teaching and assessing systems thinking is not always easy to do. Part of the challenge with assessing systems thinking is defining what is meant by term. The definition for systems thinking often varies slightly by domain. For example, systems engineering definitions may rely heavily on the focus of engineered systems or stocks, flows, and feedback loops in dynamic systems [1]. Some definitions focus more on identifying the boundary of a system and how our perspectives inform our decision on where to draw the boundary [2]. Other definitions of systems thinking are grounded in management and dealing with complexity in organizations [3]–[5] or emphasize the importance of understanding the components of systems, the relationships between components, and the overall function of the system [6]. Though there is no one definition for systems thinking, many can agree on the importance of the skill and there are often national calls to develop systems thinking skills framed as a broadly-applicable professional competency [7], [8].

For K-12 contexts, focusing on systems thinking can help better prepare students to think about complexity and real world problems they may encounter throughout their education and careers. Current research conducted by the authors of this paper indicate that current system thinking teaching approaches and assessments focus primarily on domain-specific areas, many of which ask students to define parts of well-structured problems. For example,

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assessments might focus on the water cycle and evaluate students by how well they can identify the prescribed steps of the cycle [9] or evaluate students in specific contexts related to understanding biological or ecological systems [10]. While this is a necessary and important skill, this type of activity may not lead to students transferring the systems thinking skill across domains and other contexts, and generally does not deal with the ill-structured and complex problems we often encounter in our daily lives. Furthermore, there is growing evidence that if we want students to develop these skills then we need to prioritize creating opportunities for instruction and practice explicitly and giving students feedback about ways to improve their skills [11]. Formative assessment tools provide such opportunities by operationalizing specific constructs and creating scaffolded structures (e.g., scoring rubrics) which can provide direct feedback.

II. Research Question

The purpose of this study is to pilot an instrument to assess students' systems thinking in K-12 contexts. The primary question guiding this study is: To what extent does the proposed systems thinking assessment instrument elicit and evaluate middle school students' systems thinking and reasoning pertaining to specific systems thinking constructs?

III. Theoretical Framework

The theoretical framework guiding this work in progress is defined by Grohs et al. [7]. This framework was developed from looking across multiple disciplines and includes three dimensions of systems thinking: problem dimension, perspective and problem dimensions, and time and problem dimensions. The problem dimension primarily focuses on identifying and defining the problem and the stakeholders, as well as existing needs, assumptions, and knowledge or expertise of the problem. The perspective and problem dimension focuses on how different stakeholder groups perceive the problem. The final dimension, time and problem, focuses on the historical influences of the problem as well as future, unintended consequences of solution implementations in the short-term and long-term. This framework allows for an understanding of different constructs of systems thinking and provides a structure for creating assessment.

IV. Methods

A. Context and Participants

This assessment will be piloted in the context of a summer enrichment program for middle school students (grades 6-8) in a local city public school system over the summer of 2023. The STEM portion of the program will focus specifically on heat and heat resilience where students will engage with concepts of heat, how heat is felt and experienced, temperature sensing and data analysis, and strategies to address heat. Throughout the curriculum, students will develop an understanding of the complexity of heat impacts in their communities, and will be encouraged to think about civic action and engagement to address issues related to heat. All participants of the summer enrichment program will be recruited to participate. Students' parents or guardians will be asked to provide consent for their students' data to be included in our analysis.

B. Assessment Instrument

The assessment instrument that will be piloted is based around the use of vignettes. Vignettes have been used in previous, similar work with undergraduate students followed by prompts asking them specific questions about different constructs of systems thinking [7]. Using a similar approach, vignettes were developed around the specific context for the pilot and the relevant constructs of systems thinking were identified. These constructs are:

1. Defining the problem
2. Identifying stakeholders and stakeholder perspectives
3. Recognizing community contexts
4. Identifying unintended consequences and future challenges

While there are arguably many constructs of systems thinking, these four were selected as a place to start for piloting the assessment, and based on what could be developmentally expected of middle school students. The series of three vignettes were developed so that each one increases in the scale of the scenario: personal, school, community. The vignettes and question prompts are described in the following sections.

C. Vignette 1: Define problem and identify stakeholders

In the summer, you notice where you live gets hot during the day, especially in the afternoon once the sun has been out for a while. Recently, there has been construction on the lot next door which required a tree to be removed. This tree provided a nice shade from the sun in the area where you relax and do homework but now,

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since the tree was removed, this space is uncomfortable to be in during the day.

Prompts:

1. What is the problem described in this scenario?
2. Who is affected by the problem? How are they affected?
3. Who else should care about the problem?

D. *Vignette 2: Recognize community contexts and stakeholder perspectives*

Your school is in an older building and does not have AC but many of the rooms have ceiling fans to circulate air. However, when it is warm outside, your classroom becomes incredibly hot and you have noticed it makes you more tired and you do not concentrate as well. You have asked your teachers why your school does not have AC and they reply that updating the building or building a new school would be incredibly expensive.

Prompts:

1. What is the problem described in this scenario? What is causing the problem?
2. Who is impacted by this problem?
3. How is this problem impacting the school community? How might each group who is affected by this problem feel?

E. *Vignette 3: Identify future challenges and unintended consequences*

The neighborhood next to yours is mostly tall apartment buildings, parking lots, and large expanses of pavement. Your neighborhood, while it does have apartment buildings and parking lots, seems to have more trees, parks, and green areas. You've some heard residents from the other neighborhood complain about how hot it gets when they are walking or waiting for the bus, and you've seen advisories about checking on the older people in the neighborhood when it is extremely hot.

1. To address the extreme heat the residents in the next neighborhood complain about, the city decided to take steps to increase the neighborhood's heat resilience. Among the strategies proposed was to pave over existing roads with material that would reflect solar energy and stay cooler, which should lead to a decrease in the heat the community members experience. However, the paving would require that some roads be closed for periods of time and it may take longer to pave all of the streets identified. If this solution is implemented, what are some challenges the residents in this neighborhood may face in the following weeks or months? What are some new problems that may come up? What might the long term benefits be if this plan is implemented?

F. *Pilot Data Collection*

Dyadic interviews will be the main source of data collection for this pilot. Dyadic interviews have been argued to be a strategy to bridge some of the limitations of single interviews and focus groups. Others have argued that dyadic interviewing allows participants to share experiences and reflections, be more comfortable and open, and generate conversations that can cover a wide range of topics [12]. Additionally, the data produced from dyadic interviews can be in-depth while allowing for both participants to share, which is sometimes not the case for other data collection methods such as focus groups [12]. In a typical interview scenario, it is possible younger students may feel uncomfortable being interviewed by an adult or may feel the need to be on their best behavior [13]. Therefore, utilizing a method like dyadic interviews where only students are involved can lead to better responses and help students feel more comfortable with participating.

In this context, students will be paired together at the direction of the teacher. After students read through each vignette, one student will ask the other student the question prompts and the students will be encouraged to engage in some discussion with each other. For example, Student A asks the questions for Student B to respond to, and they can engage in conversation around their own responses, views on the questions and experiences with the vignette. Students will record their conversations with voice recording equipment, and the recordings would be transcribed and analyzed by the research team.

G. *Data Analysis Plan and Anticipated Results*

The transcripts from students' conversations will be analyzed using the theoretical framework and the constructs specifically identified in the methods section. Analysis will primarily focus on the variation in students' responses as it pertains to the framework as a way to assess the instrument. Looking at how students' responses vary will be taken into consideration and if the students'

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responses are evidence that the vignettes elicit these responses. For example, we might expect to see a range of student responses, including that the vignettes are written clearly enough that students are able to respond to questions with information from the vignettes. We would hope to also see that students are able to extend their thinking beyond the information in the vignettes, and make important connections to other factors that are not explicitly stated in the vignette.

H. Limitations

There are a few limitations to this pilot. First, we recognize that students participating in this activity will be at varying stages of cognitive development. This means that we expect that some students will be able to demonstrate some abstract thinking while others may be at a stage where they can think about more concrete ideas. Therefore, it is important to recognize that their responses may not be directly representative of the vignette as a tool, but rather developmental stages. Additionally, because the context of this pilot is specific to the program, we do not anticipate that the vignettes as written will make sense in all contexts. However, as an initial exploration, using vignettes specific to the context will help provide some preliminary understanding of the usefulness of this type of tool.

V. Implications and Future Work

This research addresses a need to have a tool that can assess K-12 students' systems thinking. While there are some existing tools, there is a need to develop tools that can assess systems thinking in the context of ill-structured problems. For engineering and computing education, it is important to focus on ill-structured problems and to be able to assess students' relevant skills in dealing with these problems as many real-world contexts are not neatly packaged. Students need to be able to identify and define problems, as well as consider who is involved and how stakeholder perspectives may vary. Having a tool that can give educators an idea of where their students are in this skill development can help them provide feedback to students and can lead to discussions about complex problems and how to deal with them.

Future work will focus on the analysis of the data collected from this pilot study and the refinement of the proposed instrument through additional data collection in a different context, with different vignettes. For example, this study focuses on heat resilience in urban areas but future data collection will focus on different themes such as water access or food access, and will be collected in rural school contexts.

The data and insights collected from this pilot study will inform the development of a tool to assess K-12 students' systems thinking. The goal of this pilot study and future studies is to develop a tool that focuses more on how students deal with ill-structured, complex problems rather than well-structured problems that typically only have one correct answer. This will likely mean that students will have to draw on knowledge they have learned across disciplines and that the developed tool will not be specific to a single discipline. As more data is collected beyond the pilot study, we hope to understand more about the usefulness of vignettes to elicit student responses and as a way to evaluate their systems thinking skills. In the future, we plan to develop more vignettes that may apply across contexts while still focusing on complex, sociotechnical problems that may be relevant to students.

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