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Assessing systems thinking: A tool to measure complex reasoning through ill-structured problems

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ABSTRACT

An increasingly important aim of higher education is to develop graduates capable of addressing complex, interdependent problems. Systems thinking is a critical interdisciplinary skill that describes the cognitive flexibility needed to collaboratively work on problems facing society. Although institutions of higher education are asked to develop systems thinkers and many programs strive towards such an aim, mechanisms to assess this competency are lacking. This paper (1) presents a framework for operationalizing systems thinking competency, and (2) shares a novel scenario-based assessment tool based on the framework. The paper describes the iterative development of the community-level problem scenario and associated scoring rubric based on a set of 93 student responses. Appendices contain the full tool consisting of the problem scenario, scoring rubric, and other guiding documents to enable others to adopt the tool for research purposes or to assess student outcomes from university programs.

Critical thinking scholar Richard Paul (1993) writes, “Governmental, economic, social, and environmental problems will become increasingly complex and interdependent… The forces to be understood and controlled will be corporate, national, trans-national, cultural, religious, economic, and environmental, all intricately intertwined” (p. 13). A look across the global landscape suggests that society is indeed faced with seemingly intractable challenges, and it is argued that colleges and universities must play a central role in developing the citizen-leaders capable of complex and flexible reasoning to tackle these complex challenges (The Talloires Network, 2005). Indeed, government agencies cite needs for graduates who are capable of (a) addressing complex problems from varied perspectives; (b) collaborating across disciplinary boundaries; and (c) utilizing integrative and critical thinking skills (e.g., National Academy of Engineering, 2004; National Institutes of Health, 2006; National Research Council, 2012; National Science Board, 2010; Spellings, 2006).

Yet, many colleges and universities do not articulate interdisciplinary learning objectives, and even fewer attempt to assess these competencies beyond survey instruments aimed at self-reported behaviors and attitudes. The driving questions then become, how do we cultivate the next generation of leaders for a world of problems we currently cannot solve, and how would we even begin to know if some graduates were “more prepared” than others to face these challenges? Models and tools that facilitate independent assessment of skill development are needed to help universities better understand program impacts and to better align learning outcomes with specific needs of institutional, governmental, and private sector audiences.

In this paper we introduce a systems thinking competency framework and a scenario-based assessment tool that can be used to measure students’ skills in complex collaborative problem-solving across disciplines. Also, we describe the process and present the product of an iteratively developed scoring rubric. We share this work so that other researchers and practitioners might use and

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improve upon these tools to advance knowledge about systems thinking competency and to assess outcomes of educational programs aimed at developing leaders who thrive in complex interdisciplinary settings.

1. Literature review and conceptual framework

Due to its parallel development in several academic fields and professions, it is difficult to identify a universally accepted definition of systems thinking. Systems engineering, management, and industrial design scholars have each drawn on a similar set of constructs and principles to advance thinking in seemingly disparate fields. For example, the NASA Systems Engineering Handbook describes systems engineering as "…a way of achieving stakeholder functional, physical, and operational performance requirements in the intended use environment over the planned life of the system within cost, schedule, and other constraints" (Hirshorn, 2017, p. 3). The systemic elements inherent in this definition relate to the operationalization of technical criteria through interactions with stakeholders and/or human factors specialists within an organization who represent stakeholder interests during the design process (e.g., Coso & Pritchett, 2015; Hirshorn, 2017). This definition emphasizes the pursuit of a finite solution and places inherent value on efficiency, effectiveness, and reliability.

The work of management scholars like Peter Checkland and Peter Senge was a response, in part, to system engineering's reductionist approach and pushed for more robust consideration of the complexity and nonlinearity of many management decisions. Checkland's soft systems methodology (SSM) was an early attempt to integrate consideration of the desirability of proposed solutions with more traditional concerns for feasibility (Checkland, 1989). Underlying the SSM approach was an assumption that complex problems are better addressed when decision makers understand subsystems and their interdepencies (Checkland, 1999). Senge also drew attention to interdependencies and nonlinear relationships by highlighting the unforeseen and long-term consequences of short-term solutions; he articulated the need for managers to shift away from reactive and toward creative organizational cultures (Senge, 1987). Senge defined systems thinking as "a way of thinking about, and a language for describing and understanding, the forces and interrelationships that shape the behavior of systems" (Senge, Kleiner, Roberts, Ross, & Smith, 1994, p. 6).

With roots in industrial design and product development and deepening connections to management strategy, the burgeoning practitioner and scholarly literatures on design thinking (Kolko, 2015; Liedtka, 2015) present a new paradigm for problem solving. Design thinking (DT) echoes system engineering's consideration of users in the development process, and it references both Checkland and Senge in its attention to problem framing and recognition of multiple, imperfect solutions. In most of its variations, DT emphasizes the need for adherents to develop empathy for users and to employ iterative processes to frame problems, ideate, and refine solutions (Carlgren, Rauth, & Elmquist, 2016). As DT has grown in popularity, it has increasingly been touted as a means to achieve robust outcomes in a broad spectrum of activities. Brown and Martin (2015) observe that DT has moved beyond designing physical objects to "helping multiple stakeholders and organizations work better as a system" (p56).

Jones (2014) distinguishes between the generative orientations of systems engineering and design thinking and the analytical orientation of systems theory to call for a blended approach to address complex global issues. To this end, Jones presents a framework for systemic design, characterized by ten core principles that he aligns with systems theory and design principles. The resulting process closely aligns with the work of Stroh (2015) whose four-stage process of systems thinking for social change focuses on unpacking the complexity of social issues by considering discrepancies between the designed purpose of a system and the actual product. For example, Stroh mentions how criminal incarceration as a current public safety concern may end up contributing to significant issues for children with incarcerated parents (Stroh, 2015). Arguably, from social science perspectives such as Stroh, less emphasis is placed on the product capabilities and criteria as seen in systems engineering approaches; instead, more emphasis is placed on individual or organizational roles in contributing to and addressing social issues. Public policy scholars Schön and Rein (1994) argue that, "Because policy designing is double designing, the designers' moves must meet both the substantive requirements of problem-setting and −solving and the requirements, political and interpersonal, of sustaining the design coalition" (p. 170).

As global problems continue to grow in complexity, however, the lines between the physical and social sciences have blurred, and thus it is important to develop a framework that draws across disciplines. Social, economic, political, environmental, and community contexts must be taken into consideration when developing solutions (e.g., Jonassen, 2000; Paul, 1993), and yet discrepancies still remain between the well-structured and bounded problems of formal education and the ill-structured nature of work in the professional world (McNeill, Douglas, Koro-Ljungberg, Therriault, & Krause, 2016; Patil, Dutta, & Bement Jr., 2015). The most challenging problems that face professionals today contain combinations of such intertwined complexities and are classified in the literature as *wicked problems. Wicked problems* are characterized by (a) the unique nature of each problem; (b) the interplay between attempts to address the problem and how it is framed; and (c) the ambiguity of causality, particularly as it relates to the temporal distance between an intervention and any direct effects (Rittel & Webber, 1973). Such situations call for a metacognitive strategy—a flexible way of framing, reasoning, and acting within multiple dimensions, which we conceptualize as "systems thinking." In this paradigm, using right or wrong solutions to distinguish novice- and expert-level systems thinking is simply not possible, as these problems, by definition, do not have clear solutions; instead, an approach allowing for more differentiation of problem-solver ability might involve assessing a student's fluency in reasoning through a posed *wicked problem*.

We conceptualize this fluency by developing the Dimensions of Systems Thinking Framework, which emerged from our review of literature. The framework includes three dimensions—*problem*, *perspective*, *time*—along with measurable constructs associated with those dimensions (see Fig. 1). Extending beyond the systems engineering, design thinking, and systems thinking discussion earlier, our framework is strongly informed by problem-solving literature in engineering education, critical thinking literature in philosophy, as well as theory and scholarship related to leadership and community development, organizational studies, and public policy. In taking this interdisciplinary approach, we leverage the unique and common insights from each field to create a broadly framed

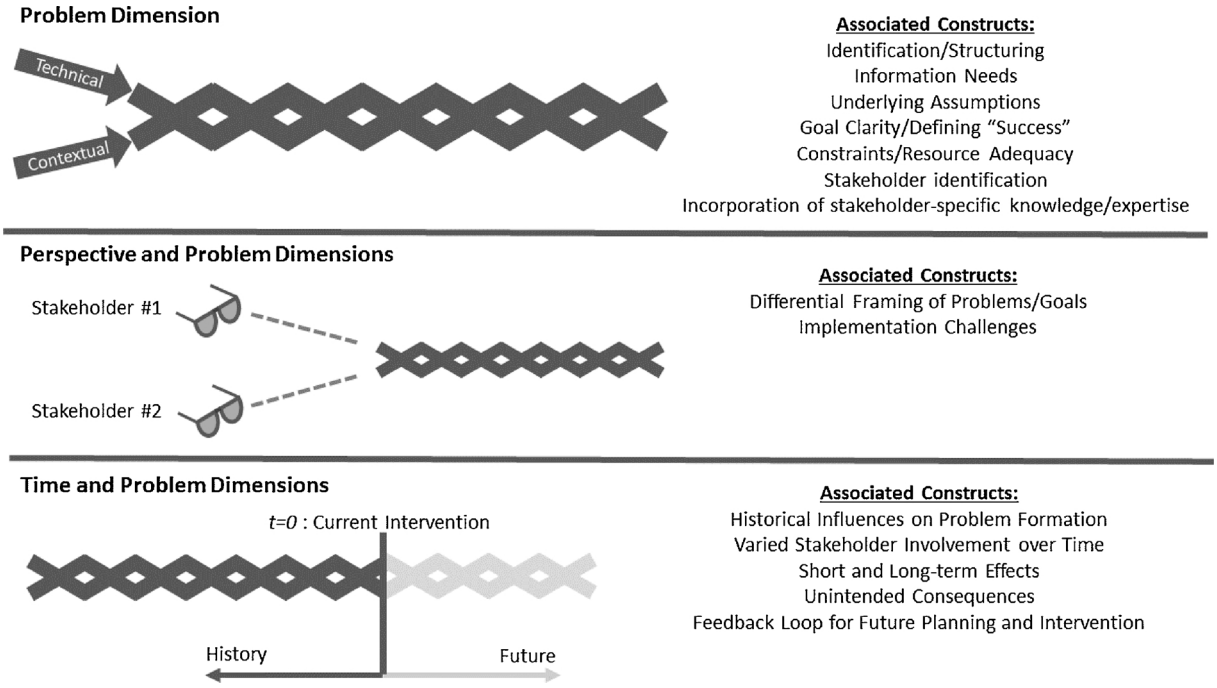

Fig. 1. Dimensions of Systems Thinking Framework based on systems thinking literature from multiple disciplines.

approach to systems thinking competency. In the sections that follow we discuss each dimension of the framework and describe the complexities that arise when these dimensions intersect.

1.1. Problem

A problem is commonly understood as a difference between the current reality and a desired goal (Jonassen, 2000), and problem-solving involves cyclical interplay between cognition and action. Problem-solving activities include defining the current and goal states, assessing one's resources (e.g., cognitive, physical), identifying additional resource needs (e.g., information), identifying constraints, and exploring underlying assumptions that influence reasoning. In presenting a model for systematic and critical reasoning, Paul (1993) asserts that an essential element of problem definition involves deciding which conceptual elements are considered and which are excluded. The systems engineering and design thinking literatures similarly highlight the importance of iterative problem-setting and boundary drawing processes as evidenced by the Royal Academy of Engineering's (RAE) first principle of "debate, define, revise, and pursue the purpose (Elliott & Deasley, 2007, p. 13)" and the emphasis on naming and framing the problem by proponents of DT (Self, 2017).

As problems become more complex and ill-structured, they are defined by intertwining *technical* and *contextual* elements. We cast *technical* elements as the specific objects, tools, knowledge, and processes employed to transform inputs (e.g., problems and resources) to outputs (e.g., solutions and consequences). This broad view of the technical elements of problems encompasses both modern constructions of technologies as scientific or engineering devices and theoretical conceptualizations of technologies. The latter, borrowed from the field of organization studies, is more inclusive, considering both system and task-level transformational processes (Hatch & Cunliffe, 2013). In contrast, *contextual* elements refer to the environment in which these technical elements are embedded, including social, cultural, political, legal, ecological, and economic features (Forester, 1984).

Because society's most pressing issues represent an intertwining of these technical and contextual elements, our framework requires both to be considered in the following constructs associated with the *problem* dimension: identification/structuring (e.g., Bransford, Sherwood, Vye, & Rieser, 1986; Simon, 1973), information needs (e.g., Voss, 1987; Wood, 1983), underlying assumptions (e.g., Paul, 1993), goal clarity/defining success (e.g., Wood, 1983), constraints/resource adequacy (e.g., Hirshorn, 2017; Jonassen, 1997; Newell & Simon, 1972), stakeholder identification (e.g., Jonassen, 1997), and incorporation of stakeholder-specific needs, knowledge, or expertise (e.g., Coso & Pritchett, 2015; Jones, 2014; Kahane, 2010). It is important to note that identifying stakeholders and incorporating stakeholder-specific needs, knowledge, or expertise are treated as separate constructs, in part because disciplinary differences may unintentionally prioritize one over the other. Generative approaches from systems engineering and DT often acknowledge stakeholders (e.g., product users) as sources of information (Brown & Martin, 2015; Kolko, 2015; Walden, Roedler, Forsberg, Hamelin, & Shortell, 2015) but rarely acknowledge their agency in the process. The framework seeks a more critical examination to ensure inclusion of voices and perspectives that may be absent, ignored, or suppressed unless specially identified as a priority. The incorporation of stakeholder-specific features in the framework addresses both the identification of

stakeholder needs and constraints and the intentional process to include stakeholders during problem solving processes (Coso & Pritchett, 2015; Schön & Rein, 1994; Stroh, 2015).

1.2. Perspective

The *perspective* dimension acknowledges that problem-solving involves the recognition of diverse stakeholders and the influence of their varied values, beliefs, and past experiences on the definition of a problem and the viability of any solution. In an effort to better understand aspects of socially-complex problems, scholars Schön and Rein (1994) investigated intractable policy controversies, attempted interventions, and the different frames of reference people use to define problems. In their paradigm, frames are defined as "underlying structures of belief, perception, and appreciation" that undergird political positions, and they claim policy decisions are often stymied because various stakeholders approach the policy issue from divergent frames that are "exempt from conscious attention or reasoning" (1994, p. 23). Senge (1987) concludes that these mental models inform the ways managers understand the behaviors, structures, and predicted effects of changes within systems.

The *perspective* and *problem* dimensions also intersect, as policy frames script the problem-setting process for each party via the assumptions and biases inherent in their subscribed narratives. Incompatible frames result not only in fundamental disagreements over problem definition but in the solutions associated with distinct framings of the problem itself. Schön and Rein (1994) advocate for policy decision making that includes active and intentional reframing and reflection by participants individually and together. They also stress that arriving at policy solutions should be an iterative process informed by recognition of limitations and constraints, variable interdependence, and intergroup trust. Drawing on Schön and Rein and expanding on the stakeholder elements described in the problem dimension, we include identification of implementation challenges as a key construct associated with the perspective dimension in operationalizing systems thinking competency.

1.3. Time

The *time* dimension refers to the specific past and future of given problems, stakeholders, and attempted solutions. Reflection and prediction are essential elements of the problem-solving process. As Paul (1993) suggests, critical thinkers must make inferences by making connections and logical jumps based on both empirical and conceptual material at hand. Moreover, the critical thinker must consider both implications and consequences, which may not be readily apparent from available information. The field of systems engineering similarly attends to these past, present, and future impacts as the RAE (Elliott & Deasley, 2007, p. 15) argues, "The legacy is part of the environment; it constrains the possible solutions but also brings experience and standards. Accommodating unforeseen future needs is hard to specify but is one of the requirements and may prevent narrow, short term thinking (p. 15)."

Time is also intertwined with the other two dimensions. The relationship between *time* and *problem* can manifest when the definition of the problem varies with time. For example, flooding might be an infrastructure problem in the short-term, but it could, in time, develop into a significant public health issue. *Time* and *problem* interactions also can present as variances in the short and long-term impacts of potential solutions and the associated unintended consequences. For example, early attempts to repair the Deepwater Horizon oil spill resulted in additional problems that had to be addressed later. *Time* can also interact with the *perspective* dimension when stakeholder involvement or problem frames vary over time. The ongoing national debate over immigration reform, for example, illustrates how changes in elected leadership can influence which individuals and groups are (and are not) intentionally invited into policy conversations.

These three dimensions—problem, perspective, and time—and their interactions provide a framework for understanding the elements of a systems thinking approach to problem-solving that is sensitive to the complex and ambiguous nature of *wicked problems*. Our framework positions systems thinking as a metacognitive strategy for flexibly and iteratively considering problems. This framework organizes our attempt to measure systems thinking ability using a scenario-based tool described in the sections that follow.

2. Methodology

2.1. Problem scenario development

We developed a purposefully designed, hypothetical problem scenario to challenge college student respondents to consider a set of information, approach problem definition, develop decision making and implementation processes, and create and evaluate potential situational solutions. The Dimensions of Systems Thinking Framework (Fig. 1) guided the scenario design and the delivery process. However, not all constructs from the framework could be feasibly embedded within the same scenario (e.g., feedback loop affecting future action is difficult to measure in a scenario administered at a single instance of time and thus is not included). Included constructs are discussed in the rubric development section.

The problem scenario is framed in a community setting, the fictitious town of Abeesee (pronounced like A.B.C.), and seeks to be accessible to diverse populations of students by reducing advantages of domain-specific knowledge in the reasoning process. Although this particular tool and setting is novel, it follows strategies similar to other domain-specific, ill-structured problem-solving assessment tools (e.g., an astronomy problem in Shin, Jonassen, & McGee, 2003). For context, the initial vignette for the situation in Abeesee is given in Fig. 2.

The scenario is structured in three distinct phases: *processing, response,* and *critique*. Though not formally modeled after a heuristic from design thinking, this phased administration of the scenario roughly aligns with Cross's (2008) stages of "exploration, generation,

Village of Abeesee Scenario

The Village of Abeesee 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 Abeesee residents. Many residents are unable to afford heat for the entire winter (5 months). A University of Abeesee 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 Abeesee 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).

Fig. 2. Village of Abeesee Scenario.

evaluation." In our instrument, the *processing* phase collects individual responses about: (1) the way respondents frame the problem in response to the vignette; (2) additional sources of information they would require before designing a solution; (3) potential measures of successful outcomes in Abeesee; and (4) stakeholders they would involve in the decision making process. The *response* phase asks for: (1) an outline of a specific plan addressing the situation; and (2) anticipated challenges to implementing the proposed plan. In the *critique* phase, respondents are asked to critique a sample plan (i.e., an "attempted solution") via prompts that would lend insight into: (1) the respondent's ability to interpret someone else's goals; (2) the ability to predict unintended consequences; and (3) the ability to judge adequacy of resources. To provide sufficient time for robust, descriptive responses, administration of the scenario tool requires approximately 30–45 min. The full scenario and associated reflective prompts are openly accessible online and are included in Appendix A.

After development, the scenario was piloted with 27 undergraduate and graduate students representing diverse disciplines and expertise to understand the nature of student responses and investigate the alignment with the intended constructs within the Dimensions of Systems Thinking Framework. Qualitative data from student responses were analyzed, and it was determined that (1) the tool elicited relevant data on each of the constructs for which it was designed, and (2) within each construct, sufficient data were available to assemble possible means of characterizing the data that allow for study of variation across responses. Thorough discussion of this pilot work is available (Grohs, 2015) and led our team to collect a larger pool of data to develop a scoring rubric that can be used to assess quality within student responses.

2.2. Rubric development

Our primary goal with this effort is to have a useful tool to measure students' systems thinking competency in an ill-structured problem-solving context that moves beyond traditional self-reported attitudes or behaviors. Encouraged that student responses to the Abeesee scenario elicited meaningful data on our constructs of interest, we began a multi-stage rubric development process following the guidelines of Arter and McTighe (2001) using a larger pool of student responses. Specifically, we collected data from 93 first year engineering students from a Global Engineering Practice course and study abroad program. We structured our rubric development in the following stages:

1. Create Rubric First Draft: A single researcher, who was not involved in original scenario development, performed qualitative analysis of one quarter of the sample to cluster responses, identify distinguishing traits of responses, and create a working first draft of the rubric based on the analysis.
2. Refine Draft Rubric for Alpha Testing: The full research team discussed the results of the qualitative analysis and the first draft of the rubric and iteratively refined rubric language, discussed exemplar responses of quality levels within each construct, and developed rating guides to create a rubric ready for alpha testing (i.e., testing with an individual not involved in the research).
3. Implement Rubric Alpha Testing: An unfamiliar rater potential user as well as the researcher from stage 1 independently scored the second quarter of data using the rubric and rating guide, recording their rationale for their scores. After scores were assigned, they discussed the scoring process and examined inter-rater scoring discrepancies that may have resulted from rubric clarity issues. Examples of the recorded rationale acknowledging discrepancies are shown in the Appendix for reference.
4. Develop Rubric for Beta Testing: The full research team discussed the results of the alpha testing and further refined the rubric language, exemplar responses, and rating guides to prepare for broader scale beta testing (i.e., testing with several individuals from different educational backgrounds).
5. Implement Rubric Beta Testing: A collection of seven faculty from service learning and graduate students studying educational research independently rated responses from the third and fourth quarters of the data pool to help us understand the time involved in rating responses and to solicit feedback about rubric clarity and usability.

This iterative and systematic approach to rubric development with several steps of testing led to a shareable product that includes (1) a Criteria and Rating Guide (i.e., traditional scoring rubric), (2) a Mapping Document that directs the rater to specific responses when assessing quality within a particular construct, (3) a bank of Working Definitions to provide additional clarity to the key distinguishing traits that are featured in the Criteria and Rating Guide across different levels of response quality, and (4) example responses with rater scores and commented rationale in to provide additional context. These documents are included in Appendices B–E respectively to facilitate adoption of the tool.

3. Results and discussion

To facilitate broader use of our systems thinking assessment tool, we briefly discuss each salient construct from the rubric and the means for differentiating different levels of response quality in the sections that follow. Following guidelines from Arter and McTighe (2001) to provide a zero anchor, the scores range from 0 to 3 with a score of 0 representing no response or an irrelevant response, and a score of 3 characterized by the qualities of an ideal response.

3.1. Problem identification

In the processing phase, the intentionally vague Abeesee scenario leaves the task of unpacking the problem to the respondent. An assortment of data is embedded (e.g., 38% of village residents have gone without heat for at least 30 winter days in the last 24 months) with no explicit intent that any piece of information is more important than another.

As respondents described perceptions of the problems and/or issues facing Abeesee, answers were diverse. Some respondents tended to frame the problem in economic terms like the affordability of heat or the average household income. Others focused on the problem's inherent environmental factors by focusing on the development of a portfolio of alternative energy sources. Across these different answers, the key markers of expertise involved the identification of both *technical* and *contextual* features of the problem as well as significant *interactions* between these features. We draw on the organizational theory literature to define *technical* features as those dealing with the knowledge and activities associated with the delivery of products, goods, or services. This scoping is contrasted with *contextual* features which are the social, political, legal, ethical, and cultural environments within which the technical issues reside. A model response identifies both *technical* and *contextual* features and discusses how they interrelate as part of problem identification.

3.2. Information needs

The information needs construct refers to the respondent's ability to identify additional information beyond what is given in the problem statement to understand and characterize the problem more fully. Scoring for this construct is based on a specific prompt in the processing phase where respondents brainstorm the additional information required to begin addressing the issues in Abeesee. Like the problem identification construct, the scoring rubric aims to understand how respondents discuss *technical* and *contextual* information needs and the degree to which they integrate these aspects. For example, asking for a comparison of the average income levels and demographic data broken down by those groups of Abeesee residents who did or did not go without heat in the past 24 months represents a complex integration that is more advanced than asking for either demographic data or average income levels in isolation.

3.3. Stakeholder awareness

Stakeholder awareness as a construct is concerned with the ability to identify and include relevant stakeholders and, in our assessment tool, is primarily explored through a specific prompt in the processing phase to identify stakeholders. In our pilot work (Grohs, 2015), we clustered responses and noted that major institutions (e.g., government, schools, charities, University of Abeesee) showed up frequently, as did specific professional roles (e.g., scientists, entrepreneurs, engineers, politicians), and the catchall of "the people" or "the community." These were further refined during the rubric development process to indicate three overarching categories of *power/politics*, *experts,* and *community*. We define *power/politics* to be an entity that provides administration, oversight, and/or governance over an organization, society, or community. *Experts* are entities or individuals who have achieved a state of "conscious competence" (Ambrose, Bridges, DiPietro, Lovett, & Norman, 2010) and a high level of mastery in a particular domain and are thus qualified and capable of giving advice and guidance regarding issues in their field of expertise. *Community* includes informal grassroots organizations, the end-users of goods and services, or responses which refer non-specifically to the people, citizens, or community voice. Additionally, we distinguish between consultation or input gathering efforts and more meaningful sustained *engagement* in collaborative work.

Ratings for the construct of stakeholder awareness place value both on a respondent's ability to identify stakeholders across the group categories (e.g., citizen voice, energy company executives, and local government officials) and the nature of engagement with the stakeholder (e.g., one-off consultation versus intentional collaboration).

3.4. Goals

Exploring the goals construct relies on the prompts where respondents (a) identify what they would expect a successful plan to accomplish and then (b) craft a plan to address the Abeesee situation. Ideal responses include both *short-term* and *long-term* goals. *Short-term* goals occur over a relatively short period of time and might be characterized as temporary or stop-gap measures focused on

the "here and now". In contrast, *long-term* goals are forward-looking and involve responses that occur over an extended period of time with a sense of permanence or continuity. Our rubric equally values both short-term and long-term goals as arguably both are needed to address complex community issues. Further, these goals are anchored with respect to some aspect of the problem(s) identified (i.e., *technical*, *contextual*, or both), so the scoring for the goal construct also places value on goals that address both technical and contextual features of problems.

3.5. Unintended consequences

This construct refers to a respondent's ability to identify possible blind spots in their own and a proposed solution provided by the research team when prompted to do so. The quality of responses is assessed similarly to other constructs in that unintended consequences can be *technical*, *contextual*, or the interaction of the two, and also can be *short-term* and *long-term* in scope. Priority is placed on responses that exhibit interaction over both short and long time scales.

3.6. Implementation challenges

As a construct, implementation challenges refers to a respondent's ability to identify expected barriers to their own proposal to address the Abeesee scenario. Rating this construct relies on the same response prompt as with unintended consequences and follows a parallel scoring scheme (i.e., *technical/contextual/interaction*, *short-term* and *long-term*). Despite these similarities, we consider the constructs distinct enough to warrant separate evaluation—specifically, implementation challenges focus on the expected barriers and necessary compromised tradeoffs while enacting a plan, whereas unintended consequences specifically require reflexive evaluation of perspectives or issues not immediately apparent in the plan and the limitations of the identified tradeoffs. An example of an implementation challenge is sustaining committee member engagement despite transportation challenges in a rural community. There should be recognition in the response of the unintended consequence that such issues might systematically limit who can meaningfully participate in the committee, and thus leave out critically important voices.

3.7. Alignment

Alignment, the final construct, refers to the degree to which a respondent identifies goals and plans that relate to their own definition of the problem in Abeesee. Whereas each of the other constructs was scored independently, alignment specifically looks across constructs. Implicit in rating this construct is that higher quality responses are internally consistent with logical connections across elements of the response such that the essence of an idea is retained throughout a response. For example, if a respondent describes the problem in Abeesee primarily in terms of fossil fuel costs but proposes a solution that installs coal furnaces in unheated homes, the response would be considered unaligned. Note that the subjective quality of the response is not evaluated (e.g., the variety of problem features identified); the measure of quality is captured on the problem identification construct of the rubric.

4. Implications for future work

The primary purposes of this study were to establish a conceptual framework for operationalizing systems thinking competency and to introduce a scenario-based tool with a scoring rubric designed to measure related constructs. The resulting Dimensions of Systems Thinking Framework is applicable across disciplines and contexts, and it has particular relevance for discussion of complex problem-solving in community contexts. After a systematic rubric development process, the scenario and assessment tool can be used and iteratively improved both to contribute to scholarship on systems thinking competency and to assess high-value learning outcomes such as those developed by community-engaged learning.

Through the discussion of each relevant construct we aimed to illustrate the rationale for rating levels in greater depth than is found on the rubric itself. We encourage researchers and practitioners to access the problem scenario, scoring rubric, and associated rating guide included in the Appendix. To continue improving the tool, we have included the ability in the online repository to report back results or share reflections from using the tool for teaching or assessment.

Another advantage to our scenario prompts, rubric, and rating guide is that they can be used with a variety of problem vignettes or could be easily adapted to examine student work in another context (e.g., the final report after a semester of project-based community service-learning). Efforts to develop other scenarios could remain at the same community-level as the Abeesee scenario or could more specifically be written for a particular context (e.g., urban affairs, fundamentals of engineering design) and still use the same prompts and rubrics. Such work could be used to understand if and how students transfer knowledge about collaborative problem-solving learned in a variety of contexts.

5. Limitations

Throughout the development of the instrument, several critical assumptions were made that warrant robust discussion. The first concerns the very notion of *measuring thinking* and is one that psychologists have long debated. The second is that of significant potential for *instrument bias* stemming from written responses to lengthy prompts as well as a scenario that may privilege some knowledge more than others.

5.1. Measuring thinking

Measuring thinking, much like the measurement of learning, is challenging and limited. A common means is to evaluate performance on a given task and use that performance as a proxy for the construct (e.g., the classic "candle problem" exploring functional fixedness and problem-solving ability from Duncker, 1945). Alternately, the "think-aloud" approach offers another method where individuals verbalize their thought processes during and/or in reflection upon some specific cognitive task (e.g., Ericsson & Simon, 1980; Kuusela & Paul, 2000). In effect, the approach of our present work is a hybrid of these two approaches where a respondent's reasoning process is captured through written responses to prompts which can then be subjectively scored to quantize the data. However, the scoring remains somewhat subjective in that raters might occasionally disagree on rubric scores; additionally, the written responses do not gather the depth of data that may be provided in a thorough think aloud protocol interview. Yet, despite these shortcomings, the purpose of this study is to lay groundwork for a validated tool, and so future work could include complementary think-aloud studies.

5.2. Instrument bias

Despite attempts to make the Abeesee scenario accessible to different populations, it is impossible to eliminate instrument bias. Because the tool involves a fictitious scenario with relevant statistics, it assumes that respondents will have sufficient contextual knowledge to interpret the vignette. Issues of heating were chosen because they are common enough to be deemed accessible by most undergraduates or graduate students at institutions of higher education in the United States; however, some respondents might be more familiar with heating related issues and thus respond differently than others in ways that are not related to systems thinking competency. Although content knowledge (e.g., understanding of climate, comfort with interpreting statistics) might privilege some disciplines or prior experiences, this effect is minimized because the tool evaluates reasoning through *dimensions* instead of seeking a particular "correct answer."

Another critical contributor to instrument bias involves written responses to the intentionally vague prompts throughout the tool. Clarity, conciseness, and limiting effects of unrelated skills (e.g., writing ability) are all general hallmarks of effective assessment tools (Miller, Linn, & Gronlund, 2009). However, because a key aspect of systems thinking competency involves how the respondent frames and addresses a given ill-structured problem, there must be a balance between framing enough for instrument clarity without over-structuring such that respondents are led to provide complexity in their responses that would otherwise not be present (Singleton & Straits, 2010).

6. Future work

Having developed a problem scenario and scoring rubric that is rooted in an interdisciplinary framework, our subsequent research will explore variation in respondents' scores across constructs to understand how systems thinking skills vary in undergraduate students. We will also seek to investigate the experiences that can help build these skills. Specifically, we identify the following immediate next steps:

(1) Collect additional data to build a large sample of participants and score with multiple raters scoring the same set of responses, following a fully-crossed design (Hallgren, 2012). From these participants, we will also collect responses to psychometrically validated scales that literature suggests would correlate with the scores on the Abeesee instrument. Examples will include the Critical Thinking Dispositions Scale (Sosu, 2013), the Systems Thinking Scale (Moore, Dolansky, Singh, Palmieri, & Alemi, 2010), and the Interdisciplinary Competence Scale (Lattuca, Knight, & Bergom, 2013).
(2) Administer the tool to a cohort of students and professionals with expected expertise in systems thinking and conduct think-aloud interviews to supplement written responses. This activity will help us better understand how participants interpret and reason through the Abeesee scenario as well as how they describe the influences or experiences that inform the reasoning process.
(3) Collaborate with experts in specific domains to develop scenarios more directly applicable to students in a particular discipline and evaluate the effectiveness of the Dimensions of Systems Thinking Framework and the Abeesee scenario prompts and rubric in assessing the desired systems thinking constructs.

Appendix A. Village of Abeesee Scenario.

A.I Vignette

The Village of Abeesee 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 Abeesee residents. In fact, many residents are unable to afford heat for the entire winter (5 months). A University of Abeesee 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 Abeesee 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).

1. A.II Prompts

1. Processing Phase

1. Given what you know from the scenario, please write a statement describing your perception of the problems and/or issues facing Abeesee.
2. What additional information do you need before you could begin to develop a response in Abeesee? Consider both detail and context of the problems/issues you identified.
3. What groups or stakeholders would you involve in planning a response to the problems/issues in Abeesee?
4. Please briefly describe the process you would use planning a response to the problems/issues in Abeesee.
5. What would you expect a successful plan to accomplish?

1. Response Phase

1. Given what you know and a budget of $50,000, develop a plan that would address the Abeesee situation maximizing the impact of your $50,000. Use a numbered, step-by-step guide, recipe-style to explain your response plan. For example: Step 1: Buy the noodles. Step 2: Boil water. Step 3: Add the noodles. Step 4: Drain the noodles.
2. On the previous page, you developed a plan. Without specifically changing your plan, reflect on it. What challenges do you see to implementing your plan? What are the limitations of your approach?

1. Critique Phase

Below, you will have been provided a plan for Abeesee that was developed by someone else.

Plan #46A

1. Develop an application process to allocate up to 100 grants of $500 (100 × $500 = $50,000) to low-income Abeesee residents.
2. Form a review committee comprised of 5 representatives from Abeesee stakeholder groups
3. Distribute $500 grants that can be used to make improvements to homes and residences to reduce exposure to low temperatures and/or make heating sources safer. Do not allow residents to use grants to pay heating costs.
4. Request documentation of improvements
5. Track “days without heat” and “deaths attributed to unheated homes” to see if there is a decline.

Please read the plan above and respond to the questions that follow.

1. Will Plan #46A solve the problems in Abeesee? Why or why not?
2. Please describe any unintended consequences that you think might result from this plan
3. What other factors do you think might influence the success of this specific plan?
4. How would you know if this $50,000 was used effectively?
5. One of the steps in Plan #46A is the formation of a review committee. What factors are important to consider in the formation of the committee?

1. Instrument Feedback

1. Please use the space below to tell us anything you would like us to know about the scenario, the questions, and the survey interface. We are particularly interested in knowing about places where question phrasing or terms were not clear.

Appendix B

See Table B1–B6.

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***	

Table B3
Rubric – Operationalizing Systems Thinking: Stakeholder Awareness.

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	

Table B4
Rubric – Operationalizing Systems Thinking: Goals and Unintended Consequences.

Construct	Criteria and Rating Guide	Rating
Goals *Prompts 5 and 6*	**0** No response was provided, or response was unable to identify clear goals **1** The response identified ***short-term*** goal/s that address only one ***technical*** or ***contextual*** (economic, or political, or environmental, or social or time only) **2** The response identified goals that are: 1. ***long-term*** and address only one ***aspect***; or 2. ***short-term*** and address both ***technical*** and ***contextual aspects***; or 3. both ***short-*** and ***long-term*** and address only one ***aspect*** **3** The response identified goals that articulates ***both short- and long-term goals*** and address ***both technical and contextual aspects***	
Unintended Consequences *Prompts 7 and 8*	**0** No reponse was provided, or response did not show potential unintended consequences **1** The response identified potential unintended consequences that cover one or more ***aspects: technical*** and/or ***contextual*** (economic, political, environmental, social, time, etc) but did not consider ***interaction*** of different ***aspects*** and issues **2** The response identified several potential unintended consequences. Responses considered/implied issue ***interaction*** of several ***aspects***, but there is notable focus on a ***single aspect*** **3** The response identified several potential unintended consequences. Responses considered and discussed issue ***interaction*** between ***aspects*** and considered both ***short- and long-term*** consequences	

Table B5
Rubric – Operationalizing Systems Thinking: Implementation Changes.

Construct	Criteria and Rating Guide	Rating
Implementation Challenges *Prompt 7*	**0** No response was provided, or response did not identify any potential implementation challenges **1** The response identified potential simple, ***short-term*** implementation challenges ***focused on one aspect: technical*** or ***contextual*** (economic, political, environmental, social, time, etc) **2** The response identified potential implementation challenges that are: 1. ***focused on one aspect*** and ***long-term***; or 2. ***focused on one aspect*** and consider both ***short- and long-term*** challenges; or 3. consider both ***technical*** and ***contextual aspects*** and ***short-term*** **3** The response identified several potential challenges that consider ***both technical and contextual aspects*** and the possible ***interaction*** between ***aspects***; response recognized possible barriers due to trade-offs between ***short-*** and ***long-term*** plans	

Table B6
Rubric – Operationalizing Systems Thinking: Alignment.

Construct	Criteria and Rating Guide	Rating
Alignment *Prompts 1, 5 and 6; Prompts 2 and 7 (secondary)*	**0** No response was provided, or identified problem, goals, and proposed plan are not aligned **1** Responses are ***aligned*** as follows: 1. identified problem is aligned with goal, but not with proposed plan; or 2. identified problem is aligned with proposed plan, but not with goal; or 3. goal is aligned with proposed plan, but not with identified problem **2** Identified problem, goal/s, and the proposed plan are ***aligned*** **3** Identified problem, goal/s, and the proposed plan are ***aligned***; information needs are aligned with the identified problem and/or the identified challenges are aligned with the proposed plan.	

Appendix C. Mapping of Constructs to Prompts.

Construct	Definition	Prompt #	Prompt	Response Rating Guide
Problem Identification	Refers to a respondent's ability to describe perceptions of the problems and/or issues facing Abeesee	1	Given what you know from the scenario, please write a statement describing your perception of the problems and/or issues facing Abeesee.	The problem statement articulates both ***technical*** and ***contextual*** problems & acknowledges ***interactions*** between and/or the complexity of issues – that problems and issues are not independent of one another
Information Needs	Refers to a respondent's ability to identify additional context/ information beyond the details provided in the scenario that are needed to address the problem identified	2	What additional information do you need before you could begin to develop a response to Abeesee?	The response idenitifies information needs that ***integrate contextual*** (stakeholder-type and time-type questions) and ***technical aspects***
Stakeholder Awareness	Refers to a respondent's ability to identify and include relevant stakeholders and the role that they will play in the problem and solution identification, planning and implementation process	3 4	What groups or stakeholders would you involve in planning a response to the problems/issues in Abeesee? Please briefly describe the process you would use in planning a response to the problems/issues facing Abeesee.	> If response includes involving engineers/experts or politicians giving input only, give a rating of (1) > If response includes engineers, politicians, and community giving input only (participation is limited to the input process); or engineers and politicians continuously engaging, but there is no community voice/involvement (or community alone, or where one of the groups is missing; participation is in the engagement process only), give a rating of (2) > If response includes engineers, politicians and the community iteratively giving input and engaging with each other to identify and implement a solution/ solutions, give a rating of (3)
Goals	Refers to a respondent's ability to identify short- and long-term goals towards addressing the problems and/or issues of the scenario	5 6	What would you expect a successful plan to accomplish? Given what you know and a budget of $50,000, develop a plan that would address the Abeesee situation maximizing the impact of your $50,000. Use a numbered, step-by-step guide, recipe-style to explain.	The response identifies ***both short- and long-term outcomes*** that are relevant to the scenario and ***covers technical and contextual*** (economic, political, environmental, social, time, etc) ***aspects***

Unintended Consequences	Refers to a respondent's ability to demonstrate flexibility in being self-critical and identifying possible blind spots of an attempted solution, and the degree to which a respondent explored possible limitations and unintended consequences	7 8	What challenges do you see to implementing your plan? What are the limitations of your approach? Please describe any unintended consequences that you think might result from this plan.	The response identified unintended consequences due to the implementation of solutions articulated in the sample plan provided that are ***both technical and contextual*** in nature. The discussion of these consequences considered ***interaction*** between aspects and the issues associated with these aspects, and articulates ***both short- and long-term consequences***.
Implementation Challenges	Refers to a respondent's ability to identify expected barriers to their crafted response to the Abeesee scenario	7	What challenges do you see to implementing your plan? What are the limitations of your approach?	The response identified several potential challenges that consider ***both technical and contextual aspects*** and the possible ***interaction*** between aspects (technical, economic, political, environmental, social, time, etc); response recognized possible barriers due to trade-offs between ***short-*** and ***long-term*** plans
Alignment	Refers to the degree to which a respondent incorporates aspects of the problem identified in responses to goals and plans	1 5 7	Given what you know from the scenario, please write a statement describing your perception of the problems and/or issues facing Abeesee. What would you expect a successful plan to accomplish? What challenges do you see to implementing your plan? What are the limitations of your approach?	Strong alignment between problem/s identified, goal/s, and proposed plan; responses to information needs are aligned with the problem identified and/or the identified challenges are aligned with the proposed plan.

Appendix D. Definition of Terms.

Term	Definition
short-term	• immediate, maybe temporary, response (goal/consequence/challenge) occurring over a relatively short period of time; • stop-gap measure; • temporal; • pertaining to now
long-term	• nature of response (goal/consequence/challenge) occurs over an extended period of time, with a sense of permanence or continuity; • discussion includes vision for the future; • forward-looking
technical	identifies/recognizes: • knowledge/information regarding scientific developments that an organization/entity can acquire in order to produce goods and services • physical objects or artifacts (e.g., equipment, tools, products, input/raw materials – including nature and natural resources, by-products) used in the production/delivery of goods and services • the knowledge (e.g., how to assemble an automobile, design a software program, operate a missile tracking system) needed to develop and apply equipment, tools, and methods to produce/deliver goods and services • activities or processes that comprise the methods of production/deliver of goods and services

contextual	**identifies/recognizes the following:** • **economic** – composed of labor markers, financial markets, markets for goods and services, financial capabilities of stakeholders (e.g. salary/income potential of end users) • **political** – distribution and concentration of power; nature of political system (e.g. democratic vs. autocratic) applicable in the area/context of the community/organization • **legal** – "defined by the consitutions and laws of the nations in which the organization conducts its business, as well as the legal practices in each of these domains." • **social** – "associated with class structure, demographics, mobility patterns, life styles, and traditional social institutions including educational systems, religious practices, trades, and professions." • **cultural** – "issues such as history, traditions, expectations for behavior, and the values of the society or societies in which the organization operates."
input	• the imparting of knowledge and expertise in support of the production of goods and services in a consultative (giving advice; power and participation is only in the giving of advice and not in making decisionss) capacity
engagement	• being "sympathetically and productively involved with communities;" • active participation in the production of goods and services, including the ability to exert influence and be involved in decision-making
community	• "arena in which people acquire their most fundamental and most substantial experience of social life outside the confines of the home." • (in the context of the scenario used in soliciting responses) entity comprised of the recipients and end-users of goods and services
power/ politics	• entity that provides administration, oversight, and/or governance over an organization/society/community
experts/ elites	• entity/individuals who have achieved a state of *conscious competence*and a high level of mastery in a particular aspect or domain (e.g., technical, economic, political, social, cultural) and are thus qualified and capable of giving advice and guidance regarding issues in their field of expertise
stakeholders	"Stakeholders are individuals, groups, and other organizations that have interests (their stake) in the activities and outcomes of the organization."
integration	recognition of the intersectionality (interconnection and overlapping) of issues and concerns across different aspects
interaction	recognition of the mutual/reciprocal action and influence between and among issues and concerns across different aspects
alignment	a logical connection exists across elements of the response (problem statement, goal, plan), such that the essence of an idea is retained across elements

Appendix E. Example 1

Example 1

ID	Construct	Prompt	Response	Rater 1		Rater 2	
				Rating	Notes	Rating	Notes
49	Problem Identification	Given what you know from the scenario, please write a statement describing your perception of the problems and/or issues facing Abeesee.	The problems that face Abeesee are a very cold climate in a remote location, where heating is very expensive. The growing price of fossil fuels does not help. There has been a problem with deaths from improper use of alternative heat sources.	2	Problem articulated technical issue (improper use of alternative heat sources) and contextual (environmental – remote location; economic – heating is very expensive, growing price of fossil fuels; health – deaths). Slightly implies interaction (growing price of fossil fuels does not help), but discussion of impact does not fully explore interaction	2	Multiple contextual aspects interacting – geographic, economic. No technical aspects.
	Information Needs	What additional information do you need before you could begin to develop a response to Abeesee?	I would want to understand more about the climate the Abeesee people live in, what type of geographical features surround them, and learn more about alternative heat sources.	1	Response focused on technical information needs (climate, geographical features, alternative heat sources)	2	Both technical and contextual with no integration
	Stakeholder Awareness	What groups or stakeholders would you involve in planning a response to the problems/issues in Abeesee? Please briefly describe the process you would use planning a response to the problems/issues in Abeesee.	The Abeesee government, the people of Abeesee, electric companies, and fossil fuel companies. I would speak with Abeesee people to get an understanding of how they live and their needs. I would then also speak with government officials and energy professionals about implementing a more feasible way to get them heat at a lower cost or consider safer ways to use alternative heat sources.	2	Response identified experts, community and power/political groups as stakeholders; process includes the various stakeholders providing input to discussion on resolution	2	Community, experts, and govt providing input, but do not appear to be engaged in devleoping the solution.

49	Goals	What would you expect a successful plan to accomplish?	Zero death rate from in home hypothermia, other alternative heat source incidents. A cheaper/safe method of obtaining heat throughout the winter, either fossil fuels or alternative heat sources.	2	Response identified technical and contextual goals, and plan includes steps for implementation short-term	2	Technical, economic, and government aspects discussed, but short term only
		Given what you know and a budget of $50,000, develop a plan that would address the Abeesee situation maximizing the impact of your $50,000. Use a numbered, step-by-step guide, recipe-style to explain.	1. Talk to the Abeesee people/2. Observe their current methods of obtaining heat/3. Speak with government officials/energy professionals about alternatives/5. Adapt solutions to Abeesee lifestyle/4. Gather feedback from Abeesee people/5. Revise/6. Develop new system/7. Educate Abeesee people about proper and improper use of alternative heating/				
49	Implementation Challenges	What challenges do you see to implementing your plan? What are the limitations of your approach?	I do not know what resources they have for possible alternative heating sources. With whatever those resources are, I do not know	1	Response focused on technical, short-term challenges	2	Both technical and contextual aspects short term.
	Unintended Consequences	What challenges do you see to implementing your plan? What are the limitations of your approach?	the sustainability and environmental hazards of them. I do not know the amount of heat these people require. Terrain may impact lines to make fossil fuels more accessible.	2	Responses cover both technical and contextual, short-term; some discussion of interaction/integration	2	Unintended consequences of environmental impact and misuse of money. Integrates the level of poverty with likelihood of unintended consequences.
		Please describe any unintended consequences that you think might result from this plan.	People may use the grants to pay heating costs. What specifies who the 100 low income Abeesee will be. If they are low income, they may need more extensive work to fix their heating problem that $500 may not cover.				

49	Alignment	Given what you know from the scenario, please write a statement describing your perception of the problems and/or issues facing Abeesee.	The problems that face Abeesee are a very cold climate in a remote location, where heating is very expensive. The growing price of fossil fuels does not help. There has been a problem with deaths from improper use of alternative heat sources.	3	All responses are aligned, mainly focused on alternative, cheap and safe sources of heat	2	These responses align in their focus on safe alternative heat sources & avoiding improper use, but responses to Information Needs and Implementation Challenges added other considerations not addressed here.
		What additional information do you need before you could begin to develop a response to Abeesee?	I would want to understand more about the climate the Abeesee people live in, what type of geographical features surround them, and learn more about alternative heat sources.				
		What would you expect a successful plan to accomplish?	Zero death rate from in home hypothermia, other alternative heat source incidents. A cheaper/ safe method of obtaining heat throughout the winter, either fossil fuels or alternative heat sources.				
		Given what you know and a budget of $50,000, develop a plan that would address the Abeesee situation maximizing the impact of your $50,000. Use a numbered, step-by-step guide, recipe-style to explain.	1. Talk to the Abeesee people/2. Observe their current methods of obtaining heat/3. Speak with government officials/energy professionals about alternatives/ 5. Adapt solutions to Abeesee lifestyle/4. Gather feedback from Abeesee people/5. Revise/6. Develop new system/7. Educate Abeesee people about proper and improper use of alternative heating/				
		What challenges do you see to implementing your plan? What are the limitations of your approach?	I do not know what resources they have for possible alternative heating sources. With whatever those resources are, I do not know the sustainability and environmental hazards of them. I do not know the amount of heat these people require. Terrain may impact lines to make fossil fuels more accessible.				

Example 2

ID	Construct	Prompt	Response	Rater 1		Rater 2	
				Notes	Rating	Notes	Rating
12	Problem Identification	Given what you know from the scenario, please write a statement describing your perception of the problems and/or issues facing Abeesee.	The base of the problem is that the residents cannot heat their homes. They lack a stable economy that provides jobs with enough salary security to afford heat. They do not seem to have a staple item or service for their community in order to gather income. An alternative way to build homes could also been a possibility.	3	The problem statement enumerates some technical concerns (cannot heat their homes, alternative way to build homes) and contextual (stable economy, salary security, afford heat, gather income). There is mention of interaction of issues within discussion of economic concerns lack of stable economy leads to inability to afford heat)	2	Contextual – economic. Technical – house design. Not interacting.
	Information Needs	What additional information do you need before you could begin to develop a response to Abeesee?	What are residents average income? What are most residents jobs? What is a staple or service of Abeesee? What are homes made of? Where is Abeesee located in context with other cities? (more detail than just remote) What are residents currently using as other heat sources besides trash?	2	Enumerated questions that are technical (what are homes made of, other heat sources) and contextual (average income, current residents jobs, location of village)	2	Both technical and contextual with no integration
	Stakeholder Awareness	What groups or stakeholders would you involve in planning a response to the problems/issues in Abeesee? Please briefly describe the process you would use planning a response to the problems/issues in Abeesee.	The country overall. The university of Abeesee. Environmentalist from the area. Architects and builders of the homes in Abeesee. I would first try to tackle a short term and long term solution. My short term would be to create a device that takes unsafe alternate heat sources and makes them safe or safer. My long term would be to boost the economy by developing a natural resource/service/good that can be sold to surrounding cities and countries in order to bring money to Abeesee.	2	Response identified community and experts as stakeholders ("country overall" is considered as community), but only role of experts is explored in plan. Discussion of role is mainly engagement	0	Experts and community (country) listed, no discussion of how they would be involved.

12	Goals	What would you expect a successful plan to accomplish?	The immediate issue of heat could be resolved inexpensively and then a long term plan to better the community, economy, and independence of the residents be set in motion.	3	Response identified both contextual and technical goals; response to goal was only contextual, but plan included technical steps and short-term implementation. There is mention of long-term consideration (over time economy should rise)	3	Both technical and economic, provides both short term and long term ideas
		Given what you know and a budget of $50,000, develop a plan that would address the Abeesee situation maximizing the impact of your $50,000. Use a numbered, step-by-step guide, recipe-style to explain.	1.) Engineer a device to make alternate heat sources safe. (1/3-1/2 of funds) / 2.) Distribute these devices to residents from most needed to least needed. / 3.) Tap the natural resources of the area through a plant that creates jobs for residents. (Majority of the funds) / 4.) Overtime the economy should rise and people will be able to afford heat for their homes.				
12	Implementation Challenges	What challenges do you see to implementing your plan? What are the limitations of your approach?	It could take time to engineer an alternate heating device. The more time spent of developing the product, the more people could die of exposure and hypothermia. It may cost a whole lot more than $50,000 to start up a plant for natural resources. Any form of job creation, however is a positive step.	3	Response considered both technical and contextual challenges and how the existence of one may result in another challenge to respond to. Challenges are both short-term and long-term	2	Both contextual and technical aspects short term mostly. Job creation could be long term, but not clear from response.
	Unintended Consequences	What challenges do you see to implementing your plan? What are the limitations of your approach? Please describe any unintended consequences that you think might result from this plan.	People may use the grants to pay heating costs. What specifies who the 100 low income Abeesee will be. If they are low income, they may need more extensive work to fix their heating problem that $500 may not cover.	3	Response talked about technical and contextual consequences; both short-term and long-term challenges, consequences and limitation; aspects are integrated	1	Multiple consequences, no interaction

12	Alignment	Given what you know from the scenario, please write a statement describing your perception of the problems and/or issues facing Abeesee.	The base of the problem is that the residents cannot heat their homes. They lack a stable economy that provides jobs with enough salary security to afford heat. They do not seem to have a staple item or service for their community in order to gather income. An alternative way to build homes could also been a possibility.	1	Problem and goal are aligned, but plan has a slightly different focus	3	All of these responses consistently approach the problem in a two-fold manner, addressing both the immediate problem of heating and the bigger challenge of the economy.
		What additional information do you need before you could begin to develop a response to Abeesee?	What are residents average income? What are most residents jobs? What is a staple or service of Abeesee? What are homes made of? Where is Abeesee located in context with other cities? (more detail than just remote) What are residents currently using as other heat sources besides trash?				
		What would you expect a successful plan to accomplish?	The immediate issue of heat could be resolved inexpensively and then a long term plan to better the community, economy, and independence of the residents be set in motion.				
		Given what you know and a budget of $50,000, develop a plan that would address the Abeesee situation maximizing the impact of your $50,000. Use a numbered, step-by-step guide, recipe-style to explain.	1.) Engineer a device to make alternate heat sources safe. (1/3-1/2 of funds)/2.) Distribute these devices to residents from most needed to least needed./3.) Tap the natural resources of the area through a plant that creates jobs for residents. (Majority of the funds)/4.) Overtime the economy should rise and people will be able to afford heat for their homes.				
		What challenges do you see to implementing your plan? What are the limitations of your approach?	It could take time to engineer an alternate heating device. The more time spent of developing the product, the more people could die of exposure and hypothermia. It may cost a whole lot more than $50,000 to start up a plant for natural resources. Any form of job creation, however is a positive step.				

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