A Structure for Assessing Systems Thinking

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Introduction

Many educators agree on the importance of systems thinking. Indeed, it has reached buzzword status, with many state and national educational guidelines acknowledging the importance of systems thinking skills. Recent evidence of the support for systems thinking can be seen in *Next Generation Science Standards* (NGSS), which now contain "cross-cutting concepts" that sound very much like systems thinking, including one explicitly on "systems and systems models" (NGSS, 2013).

However, even though the foundational concepts and methods of systems thinking have been around for decades (e.g., Forester 1961), progress toward a standard way of assessing systems thinking skills in a way that translates to broader educational goals has been slow. As a result, systems thinking has remained a somewhat nebulous goal for educators, who may be interested in systems thinking in the abstract, but unsure of how to implement it productively into their classrooms. Anecdotally, educators who are interested in incorporating systems thinking into their curricula express an interest in more specific, longitudinally connected objectives so that progress can be measured. Without a clearer system of progress and evaluation, the rate of adoption of systems-oriented curriculum by educators will continue to be disappointing to systems proponents.

In this paper we suggest a structure for evaluating the level of systems thinking in students. Designing such a structure requires clarity with regard to educational goals and objectives. In short, we must ask, what is the long-term goal of systems-oriented curriculum, and what are reasonable shorter-term, achievable objectives? To answer these questions, we sought guidance from educational efforts in traditional disciplines. In the front matter of *Next Generation Science Standards*, the authors observe:

> Never before has our world been so complex and science knowledge so critical to making sense of it all. When comprehending current events, choosing and using technology, or making informed decisions about one's healthcare, science understanding is key. Science is also at the heart of the United States' ability to continue to innovate, lead, and create the jobs of the future (NGSS 2012).

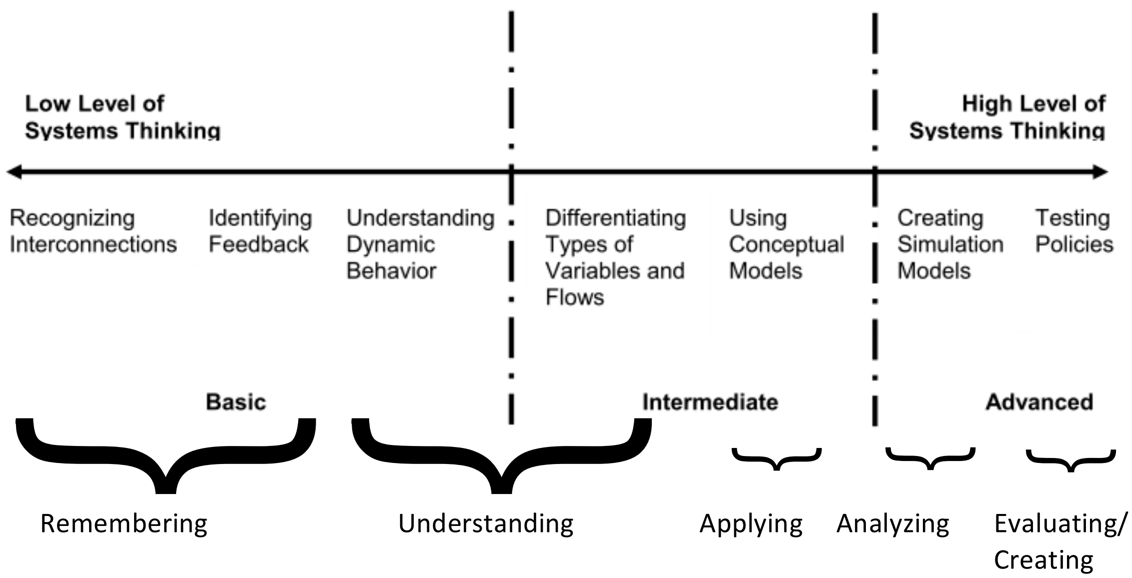
Note that the authors include two overlapping goals: 1) the importance of scientific understanding simply to be an informed and participating member of society and 2) the importance of enabling a large pool of students to become the scientific leaders and professionals of tomorrow. In other words, all students should understand the basics of biology, ecology, chemistry, and physics enough to understand the scientific aspects of contemporary issues regarding, for example, human and environmental health. In addition, a significant proportion of students must be motivated and competent to go beyond this basic understanding to become the scientific innovators of the future.

Proponents of systems thinking have a parallel set of challenges. While some may dream of a society proficient in computer modeling of complex systems, educators would be wise to identify more modest goals as well. For some students, these modest goals may be the extent of their systems thinking, while for future innovators and leaders they will be stepping stones to more sophisticated study of complexity. In either case, systems-oriented curriculum will stagnate until these intermediate goals are identified and explained. In this article we suggest a structure for assessing and documenting students' progress through these intermediate goals.

Evaluating Systems Thinking

One can view systems thinking skills as a subset of critical thinking skills that help individuals make "reliable inferences about behavior by developing an increasingly deep understanding of underlying structure" (Richmond, 1994, p. 6). Numerous educators and scholars have offered sets of specific skills that collectively comprise systems thinking (e.g., Maani and Maharaj 2004; Assaraf and Orion 2005; Riess and Mischo 2010). Most characterizations borrow extensively from Richmond's seven essential systems thinking skills (1993;1994; 2000), which outline the developing maturity of a systems thinker. With this in mind, Stave and Hopper (2008) suggest a similar system to be used as a taxonomy of systems thinking skills which parallels Bloom's taxonomy of learning. Figure 1 shows Stave's and Hopper's proposed taxonomy along with the suggested level of systems thinking assigned to each.

Figure 1: Proposed taxonomy of systems thinking skills from Stave and Hopper (2008)



Stave and Hopper (2008) report that when they presented this taxonomy to systems experts, many of the criticisms stemmed from disagreement over the proper order of the skills with some questioning whether systems thinking can be represented as a single continuum at all and suggesting that multidimensional space may be necessary. These criticisms are interesting in light of the wide acceptance of Richmond's essential systems thinking skills. While it is clear that some skills are more fundamental and may need to be acquired before other skills, the interesting questions are what determines mastery of these basic skills? And are these skills sequential or, as some have argued with Bloom's Taxonomy (Paul 1995), do learners practice many of these skills concurrently as they improve their abilities to think in systems?

While a continuum of systems thinking skills may be useful as a loose guide to the development of systems thinking, we suggest that as an evaluative tool, it presents an overly simplified image of students' progress as they learn about systems. Therefore, providing a scale of measurement for each systems thinking skill may be a more fruitful step toward developing a system for evaluating systems thinking interventions.

Our goal is to develop a system of evaluation that can measure a student's proficiency in a complicated set of interrelated skills and communicate the results in a simple and easily understood way. This challenge is similar to that of measuring literacy. Reading requires a multitude of interrelated skills and knowledge that the National Center for Education Statistics (NCES) aggregates into four levels of competency. We have adopted a similar approach to assessing literacy in systems thinking. The sections that follow focus on a set of systems thinking skills similar to those proposed by Stave and Hopper (2008)[1]. For each skill, we describe four levels of literacy with the same labels as the NCES system.

Skill 1: Recognizing Interconnections

This skill refers to individuals' ability to identify key connections between parts of a system. Lacking training in systems thinking, even highly educated adults tend to have tunnel vision, focusing on narrow chains of causality and failing to apprehend the impacts of our actions beyond our narrow focus (Plate 2010).

Below Basic Systems Literacy	Recognizes only linear connections; does not look for connections not included in prior beliefs
Basic Systems Literacy	Includes some non-linear connections in understanding of causal structure of a system; can understand an explanation of a system's behavior in terms of non-linear causal structures
Intermediate Systems Literacy	Includes many non-linear connections in one's understanding of the causal structure of a system; actively looks for connections beyond prior beliefs; can explain a systems behavior in terms of non-linear causal structures
Advanced Systems Literacy	Can develop a quantitative model of complex systems that provides insights into how impacts will ripple across a system

Skill 2: Identifying Feedback

Some of those interconnections that lie beyond our tunnel vision combine to form feedback loops, which can play a significant role in the behavior of a system. Systems thinking requires identifying those feedback loops and understanding how they can impact the behavior of a complex system.

Below Basic Systems Literacy	Little or no understanding of the role that feedback plays in a system
Basic Systems Literacy	Understands the basic role of feedback in a system; can understand an explanation of a system's behavior in terms of feedback
Intermediate Systems Literacy	Can identify feedback loops in complex systems and explain a system's behavior in the context of those feedback loops
Advanced Systems Literacy	Can incorporate multiple feedback loops in quantitative models to predict the varying influence of such feedback at different points in time

[1] The "Creating Simulation Models" skill included by Stave and Hopper (2008) is not included here, since creating quantitative computer models is incorporated in this set of systems thinking skills.

Skill 3: Understanding Systems at Different Scales

This skill represents the first deviation from Stave's and Hopper's (2008) taxonomy. Often descriptions of systems thinking involve the ability to observe a system at multiple scales. Garret Hardin's famous tragedy of the commons results from the inability of people to understand the system beyond the individual scale. This skill is not entirely different from Richmond's forest thinking—the ability to zoom out and understand the system's behavior in a broad scale and then to zoom back in to understand the details.

Below Basic Systems Literacy	Tends to interpret system behavior on a single scale (typically individual and short-term)
Basic Systems Literacy	Understands that the behavior observed at any specific scale of a system is affected by broader and narrower levels of scale
Intermediate Systems Literacy	Can explain the behavior of a system in terms of interconnections between variables at multiple scales
Advanced Systems Literacy	Can incorporate behavioral interactions at multiple scales into a quantitative model

Skill 4: Differentiating types of stocks and flows

The term *stocks* refers to any storage or pool within a system. This can be something physical, such as nitrogen in a lake, to more abstract concepts, such as a stock of money in an account, or even a stock of public trust in government. *Flows* represent changes in levels of a stock. Those untrained in systems are often surprised by delayed responses of complex systems. These delays can often be easily understood when one views a system as a set of stocks and flows.

Below Basic Systems Literacy	Little or no understanding of the relationship between stocks and flows
Basic Systems Literacy	Has a conceptual understanding of the distinction between stocks and flows and can follow an explanation of a systems behavior in the context of the interactions between multiple stocks
Intermediate Systems Literacy	Has a conceptual and practical understanding of stocks and flows and can interpret the behavior of a system based on this understanding
Advanced Systems Literacy	Can develop a model with multiple stocks and flows and use that model to make valid inferences about the behavior of the system

Skill 5: Understanding Dynamic Behavior

Complex systems tend to go through long periods of stability with little change and relatively short periods of rapid change (Gunderson and Holling, 2001). These rhythms are the result of changes in stocks which allow different feedback loops to become stronger or weaker drivers of a system. Without any systems training, our mental models tend to be static, so we fail to include these rhythms in our decisions (Moxnes, 1998).

Below Basic Systems Literacy	Has a static mental model of a system; does not incorporate the idea of change over time
Basic Systems Literacy	Has a basic conceptual understanding that systems change over time; can understand explanations of a system's behavior in terms of non-linear causal structures, feedback, and stocks and flows
Intermediate Systems Literacy	Has a thorough understanding of how systems change over time, which includes fast- and slowly-changing variables and delayed feedback; can develop reasonable hypotheses about a system's behavior in the context of non-linear causal structures, feedback, and stocks and flows
Advanced Systems Literacy	Can develop quantitative models to test hypotheses and explore scenarios regarding how a system may change over time.

Skill 6: Creating Simulation Models

Hirsch (2006) argues convincingly that experience with pre-packaged simulations may be a more effective way of introducing systems thinking skills than model-building. Still, few would deny the importance of being able to create computer simulations for more advanced systems thinking (Sterman, 2002). For this reason, we have incorporated simulation modeling at the "Proficient" level of other skills. However, working with pre-packaged simulations and creating more basic simulation models may be a significant part of a student's training in systems thinking, and there is certainly a learning curve involved with these skills. Therefore, we follow Stave and Hopper's (2008) lead, including model-building as a separate skill as well.

Below Basic Systems Literacy	Cannot interpret behavior in a simulated computer model; cannot represent complex systems in a diagram
Basic Systems Literacy	Can interpret the behavior of a basic pre-packaged simulation and describe how the structure of the system contributes to that behavior; can create simple simulation models involving a handful of stocks and flows and use the model to explain the system's behavior
Intermediate Systems Literacy	Can interpret the behavior of more sophisticated pre-packaged simulations in the context of system structure; can create simulation models of systems that are sufficiently complex to make computer simulations required for making reasonable projections regarding how the system will behave over time; can use the computer model to test hypotheses and glean insights about the behavior of the system
Advanced Systems Literacy	Can observe a system and collect the data needed to create a simulation model of highly complex systems with numerous stocks and flows; can use the model to test hypotheses and glean insights about the behavior of the system

Skill 7: Incorporating Systems Thinking into Policies

Both skills 5 and 6 require some level of proficiency of the other skills. Skill 7 implies incorporating inferences from systems thinking into one's decision-making process. As one improves at skills 1 through 5, she should be able to apply those thinking skills to make more informed decisions about her behavior in the complex systems in which she lives.

Below Basic Systems Literacy	Does not apply understanding of the complexity of a system when making decisions
Basic Systems Literacy	Applies systems thinking to personal decisions and can discern the likely effects of policies at multiple scales
Intermediate Systems Literacy	Applies systems thinking to personal decisions and uses systems concepts to assess broader policies; Can understand explanations of policies in terms of results from quantitative models
Advanced Systems Literacy	Can develop quantitative models of complex systems and use them as tools to make valid inferences about various competing policies

The Advantages of Using a Standardized Structure for Evaluation

We see this system has having value in numerous ways. First, it can provide a sense of structure and foster longitudinal connections by which students build their systems thinking skills over multiple educational experiences and even multiple years. Most implementation of systems-oriented instruction taking place today is in the form of episodic activities that do not connect directly to specific long-term educational goals in the context of systems thinking. Longitudinal connections regarding systems thinking can help teachers place current systems-oriented activities within the context of long-term goals.

Second, it can serve as a tool for improving systems-oriented instruction. A systems-thinking lesson need not address all of the skills at once. Current assessment of systems interventions are problematic because they do not seem to connect directly to each other or to broader educational goals or even to a shared and explicit set of systems thinking goals. Providing a common structure to the evaluation of these interventions can help educators identify effective methods and activities for achieving their goals within the context of specific systems thinking skills.

Third, it can provide a greater degree of legitimacy to systems thinking skills. If a teacher claims that a student is proficient at geometry at the tenth-grade level, educators from across the country know, within reason, what that means. Proficiency at systems thinking needs to have the same level of consistency.

Fourth, it helps to bridge systems thinking with the broadly accepted Next Generation Science Standards, as well as other standardized educational benchmarks which mention systems thinking concepts, but do not address them with the level of detail and longitudinal structure needed to make them useful to a broader pool of educators. Developing such connections can foster broader adoption of systems-oriented curriculum. Few educators speak negatively of systems thinking; they simply do not know how to contribute to the goal of improving systems thinking in a meaningful way. With this standardized structure for assessing systems thinking, more educators will be able to identify how they contribute to the larger goal of bringing students to basic, intermediate, or proficient levels of systems literacy.

Conclusion

Following the assessment models provided by more established fields of learning, such as science and literacy, provides practical advantages both in the further development of system-related curriculum and in the adoption of systems thinking across a broader range of educators. Certainly, there would be some disagreement as to the specific details indicated at each level of systems thinking proficiency. Indeed, our goal here is to encourage further discussion in that direction. Research findings could be useful in the development of measurable indicators for each skill and each level of proficiency. Additional work on effective strategies that teachers can use to engage learners in these skills will also be needed. However, such discussion should not divert attention from the need to have a broadly applicable, easily understood system of assessing systems thinking.

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