What Constitutes Systems Thinking?
A Proposed Taxonomy

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Abstract

This paper proposes a taxonomy of systems thinking for use in developing and measuring the effect of systems thinking educational efforts. The taxonomy was derived from a review of the system dynamics literature and interviews with systems educators. Although there is no single definition of systems thinking in the system dynamics community, there is some consensus around seven key components of systems thinking. We map these components onto Bloom's taxonomy of educational objectives to create the proposed taxonomy of systems thinking, then use this taxonomy to identify indicators of achievement at each level and tests to measure achievement. This is the first step in developing more standard assessment measures for systems thinking interventions.

Introduction

System dynamicists believe strongly in the power of the systems paradigm to improve the way people operate in the world. In addition to providing managers with systems tools, many systems practitioners also aim to change the way people think about problems. As Dana Meadows (1991:3) put it: "... if we want to bring about the thoroughgoing restructuring of systems that is necessary to solve the world's gravest problems ... the first step is thinking *differently*. Everybody thinking differently. The whole society thinking differently."

What Meadows describes is a systemic and dynamic way of thinking, often referred to as "systems thinking." But although the goal of getting people to think more systemically is broadly shared in the system dynamics community, the term "systems thinking" is used in a variety of sometimes conflicting ways. For example, some system dynamicists see it as the foundation of system dynamics

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as well as a number of other systems analysis approaches; others see systems thinking as a subset of system dynamics.

As George Richardson points out in the introduction to the 1994 “Systems Thinkers, Systems Thinking” special issue of the *System Dynamics Review*, the idea of thinking systemically about problems has a long history in many fields. He notes the term *systems thinking* only began to be used in the system dynamics field in the late 1980's. The editors of the special issue noted that “..few inside the field of system dynamics, or outside in the larger systems thinking communities, have a definition of the phrase that all would accept.” Their goal for the 1994 special issue was to provide a forum for major systems thinkers to focus on key systems thinking characteristics and problem solving approaches and to “..produce the richest possible set of views on what systems thinking is, what it could be, and how individuals and groups get better at it (1994:96).”

More than a decade after the special issue, there still is no single definition of systems thinking that all in the system dynamics community would accept. Why does that matter? Without a definition that specifies systems thinking, it is difficult to determine whether or not someone “gets better at it”. That is, without a yardstick against which to measure the level of systems thinking achieved by individuals and groups, it is hard to evaluate the effect of our efforts to facilitate systems thinking.

This paper presents our efforts to describe a continuum or set of ordered characteristics of systems thinking that can be used to determine a person’s level of systems thinking. It arises from a project we began recently to promote a more systemic understanding of environmental issues in Southern Nevada. The immediate audience is the students in the introductory Humans and the Environment course at UNLV, and the broader audience is the population of the Las Vegas Valley. As we began working on the project, we found ourselves wrestling with the questions: How can we determine an individual’s level of systems thinking at any point in time? How can we change the way people think? How will we know when we have succeeded? We concluded that we needed to know more about the attributes that characterize a systems thinker, the ways that others have measured those attributes, the kinds of educational interventions that others have used to promote those attributes, and the relative success of different interventions for promoting different attributes. This paper focuses on the first step: examining the attributes that characterize a systems thinker.

The discussion has practical implications for all systems educators. Systems thinking and system dynamics interventions have been implemented in schools at all levels for the past 20 years. This implementation has been on a small scale and grown slowly. Part of the reason for the slow growth is the lack of confidence the larger educational community has in these techniques to improve education (Zaraza and Guthrie, 2002). Although researchers have shown qualitatively that systems thinking improves critical thinking and decision-making skills (e.g., Chang, 2001; Costello, 2001; Costello *et al.*, 2001; Draper, 1991; Grant, 1997; Hight, 1995; Lannon-Kim, 1991; Lyneis and Fox-Melanson, 2001; Lyneis, 2000; Stuntz, Lyneis, and Richardson, 2001; Waters Foundation, 2006), the broader educational community remains to be convinced of the value of systems thinking. In addition to developing more concrete ways to demonstrate the value of systems thinking, we need to be able to demonstrate that educational interventions <u>are</u> developing systems thinking skills. If we want to evaluate the effectiveness of a given intervention, or compare interventions, we need to know how to measure a person's baseline ability to think systemically and dynamically, then determine how that ability changes after an intervention. To measure someone's level of systems thinking, we need to know what constitutes systems thinking and how to measure its components.

We started with the assumption that a standard way of measuring systems thinking characteristics already existed. However, a brief review of the literature and interviews with systems educators at the 2006 Systems Thinking and Dynamic Modeling for K-12 Conference, showed that there was great diversity in the way educators were using and measuring systems thinking characteristics. We then did a more thorough review of the systems literature and turned to a well-known measurement approach in the educational literature to develop the Taxonomy of Systems Thinking characteristics proposed here. We propose this taxonomy as an initial framework for assessing an individual's level of systems thinking.

Phase I: Polling Our Colleagues

Our initial review of the literature on systems thinking yielded the following list of systems thinking characteristics:

Initial List of Systems Thinking Characteristics

A systems thinker:

1. Thinks in terms of "wholes" rather than "parts" (Richmond, 1997)
2. Recognizes/seeks to understand interconnections and feedback (Ossimitz, 2000; Potash and Heinbokel, 1997; Richmond, 1997; Sweeney and Sterman, 2000)
3. Understands the concept of dynamic behavior (Ossimitz, 2000; Potash and Heinbokel, 1997; Richmond, 1997; Sweeney and Sterman, 2000)
4. Thinks in terms of the system as the cause of its behavior (Ossimitz, 2000; Richmond, 1997; Sweeney and Sterman, 2000)

5. Understands the way system structure generates system behavior (Ossimitz, 2000; Richmond, 1997)

After deriving this list, we solicited input from other systems educators about whether the list was complete, and how it might be developed into a framework for evaluating systems educational efforts. We interviewed participants at the 2006 Systems Thinking and Dynamic Modeling for K-12 Conference, in Marlboro, Massachusetts. The attendees were systems educators whose professional effort focuses on trying to incorporate systems concepts in to the K-12 curriculum. Conference attendees represented a wide spectrum of experience and expertise in the field of systems thinking.

We surveyed approximately 75 conference participants using a three-part questionnaire. Particular effort was made to contact keynote speakers and small-group discussion leaders. The purpose of this survey was to define the characteristics of a systems thinker and identify a method to measure a person's level of systems thinking.

The questionnaire asked respondents to comment on and rank the initial list of systems thinking characteristics, comment on the idea of a continuum of systems thinking skills, and review proposed questions for determining a person's level of systems thinking. The first section asked participants rank the characteristics in order of importance and add any critical characteristics they thought were missing. In the second section, participants were asked for feedback on Figure 1, an initial continuum of systems thinking skills. The continuum was intended to represent the endpoints of a range of systems thinking, where 0% represents someone who is not at all a systems thinker and 100% would represent a fully realized systems thinker. We asked respondents how they might place a person on this continuum.

Figure 1: First Cut at a Systems Thinking Continuum

Level of Systems Thinking

0%	**100%**
not at all a systems thinker	a fully realized systems thinker
See things, not relationships	See relationships rather than things
Sees Cause-effect relations as one-way	Sees cause-effect relations as reciprocal
One cause/one effect	Multiple causes/multiple effects
External events cause system Reaction	System structure causes system behavior

Results

Systems Thinking Characteristics

Although we surveyed approximately 75 individuals, only fifteen completed the questionnaire, and only six ranked the characteristics. Most respondents said they did not feel they had the knowledge to answer the questions or had not thought about the ideas we presented. They found ranking the five characteristics to be difficult. Table 1 shows the responses from the six who did give full rankings.

Table 1: Ranked Systems Thinking Characteristics Responses from Complete Surveys

Respondent	Whole vs. Part	Interconnections and Feedback	Dynamic Behavior	System as Cause	Structure Generates Behavior
B1	2	3	4	5	2
C1	2	1	5[1]	3	4
D2	1	2	3	5	4
D3	4	1	2	5	3
E3	6[2]	1	3	5	4
E4	2	1	1	1	1
Mode	2	1	3	5	4

1. Respondent C1 ranked "Dynamic Behavior" last, noting that this is an underlying assumption, not a "characteristic."
2. Respondent E3 added "Delays" to the characteristic ranking as #2.

Most people we spoke with did not want to rank the characteristics. They stressed that all the characteristics are important and none can be ignored. Some felt that this type of listing was too linear and violated systems thinking concepts. They agreed with the characteristics themselves but thought of them as interconnected rather than individually.

One respondent ranked Interconnections and Feedback as the most important attribute and noted that if a person could easily recognize interdependencies, then the other attributes would likely fall into place quickly and easily. Another divided the five characteristics into two tiers – strong indicators and weak indicators. Falling into the first tier as strong indicators of systems thinking were Wholes vs. Parts, System as a Cause, and Structure Generates Behavior. The second tier, weak indicators, included Interconnections and Feedback, Dynamic Behavior, and a characteristic added by the respondent, Recognizing Paradigms.

A third of the respondents suggested adding Delays to the list of systems thinking characteristics. This may have been influenced by a presentation by one of the keynote speakers that discussed the importance of delays.

Systems Thinking Continuum

Respondents found it difficult to answer our question about how to place an individual on the systems thinking continuum. The majority of respondents asked: “How are you going to evaluate that?” Several respondents had suggestions or opinions about the continuum, but none had specific suggestions on how to determine where an individual would fall on it. One respondent defined movement along the continuum as hitting the following cognitions: 1. understanding how something works, 2. determining the important aspects and variables of a complex issue, and 3. recognizing the interdependencies in the system.

The respondent who broke the attributes into two tiers thought that someone would need to possess all the characteristics in the first tier, strong indicators, to get at least to the halfway point on the continuum. If the person possessed the characteristics in the second tier, that person would move further along the continuum. The person’s placement would be determined by the number of attributes the subject displayed. By comparison, a different respondent recommended that the characteristics ranked the lowest would be essential to make it halfway along the continuum. Although individuals had a difficult time placing people along the continuum, there was a general consensus that placing a systems thinker along a continuum was a good idea.

Phase I Conclusions

The purpose of the questionnaire was to survey practitioners and experts in the field of systems thinking to develop a definition of systems thinking and a way to measure where a person falls on a systems thinking continuum. We found that there was little consensus and few ideas about these concepts. Although a ranking of systems thinking components could be established from the six completed surveys, over 75 attendees were approached to complete the questionnaire. We realized that in order to measure a person’s level of systems thinking, we needed to start with a more specific definition of systems thinking characteristics.

Phase II: Literature Review of Dominant Themes

Our second step was a more thorough review of the systems thinking literature. Many authors write about systems thinking in general terms; however, few offer definitions of systems thinking that specify components or discuss how they might be ordered. We focused on those who identified specific components or characteristics of systems thinking and discussed how they might be ordered. Table 2 shows the dominant components that emerged from our review of the publications through May 2007 that specifically identify components of systems thinking2. The components are arranged roughly in order from more basic to more advanced systems thinking characteristics as described by the authors. That is, most authors see these characteristics as building on one another, although there are some differences of opinion about the order of certain components.

Some authors are not represented in Table 2 because they did not specifically define systems thinking. For example, Daniel Kim has written many articles about systems thinking archetypes and tools (e.g., Kim 1994) but he does not provide a definition of systems thinking. Senge (1990:7) describes systems thinking as "a conceptual framework, a body of knowledge, and tools that have been developed to make the full patterns clearer". Goodman et al. (1994) describe how to design a systems thinking intervention but do not clearly specify the objectives of the intervention. Most systems authors base their discussions on systems thinking on Richmond's (1991, 1993, 1994, and 1997) description of systems thinking components.

The seven systems thinking components or characteristics around which a consensus seems to exist in the literature are:

1. Recognizing Interconnections

The base level of thinking systemically is recognizing that systems exist and are composed of interconnected parts. This includes the ability to identify parts, wholes and the emergent properties of a whole system. A number of authors used the analogy of being able to see both the forest and the trees. Recognizing interconnections requires seeing the whole system and understanding how the parts of the system relate to the whole.

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2 In a 1994 essay entitled "What is Ecosystem Management?", R. Edward Grumbine presented a meta-analysis of the evolving concept of ecosystem management. He examined the historical development of the concept, its dominant themes, and practical policy implications. Ecosystem management is similar to systems thinking in that its proponents see it as a "fundamental reframing" of how humans work with nature (Grumbine 1994:27). The systems community sees systems thinking as a fundamentally different way of understanding and working with systems of all kinds. We adapted Grumbine's approach to presenting the dominant themes in the literature in our attempt to clarify and specify the definition and components of systems thinking.

2. Identifying Feedback
This characteristic includes the ability to identify cause-effect relationships between parts of a system, describe chains of causal relationships, recognize that closed causal chains create feedback, and identify polarity of individual relationships and feedback loops.

3. Understanding Dynamic Behavior
A key component is understanding that feedback is responsible for generating the patterns of behavior exhibited by a system. This includes defining system problems in terms of dynamic behavior, seeing system behavior as a function of internal structure rather than external perturbations, understanding the types of behavior patterns associated with different types of feedback structures, and recognizing the effect of delays on behavior.

4. Differentiating types of flows and variables
Simply recognizing and being able to describe causal relationships is not sufficient for a systems thinker. Understanding the difference between, being able to identify rates and levels and material and information flow, and understanding the way different variables work in a system is critical.

5. Using Conceptual Models
Being able to explain system behavior requires the ability to synthesize and apply the concepts of causality, feedback, and types of variables.

6. Creating Simulation Models
The ability to create simulation models by describing system connections in mathematical terms is an advanced component of systems thinking according to some authors. Others see simulation modeling as beyond the definition of systems thinking. This category includes the use of qualitative as well as quantitative data in models, and validating the model against some standard. It does not specify which type of simulation model must be used.

7. Testing Policies
Most people see the use of simulation models to identify leverage points and test hypotheses for decision making as the full expression of systems thinking. This includes the use of simulation models to understand system behavior and test systemic effects of changes in parameter values or structure.

TABLE 2. Key Characteristics of Systems Thinking

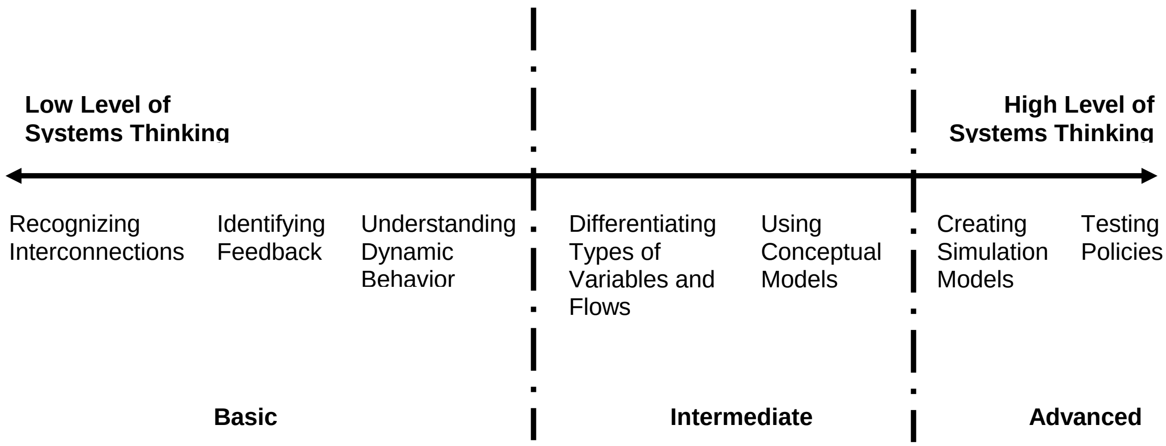
	Recognizing Interconnections	**Identifying Feedback**	**Understanding Dynamic Behavior**	**Differentiating types of flows and variables**	**Using conceptual models**	**Creating simulation models**	**Testing policies**
Citation	Seeing the whole system, understanding how parts relate to and make up wholes, recognizing emergent properties	Recognizing/ identifying interconnections and feedback	Understanding the relationship between feedback and behavior, including delays	Understanding the difference between rates and levels	Using general systems principles to explain an observation	Describing connections in mathematical terms, using both qualitative and quantitative variables	Using simulation to test hypotheses and develop policies
Assaraf and Orion 2005	X	X	X		X		
Cavaleri, Raphael, and Filletti 2002	X	X	X	X	X	X	X
Checkland and Haynes 1994	X						
Costello, 2001	X	X	X				
Draper 1993	X	X	X	X	X	X	X
Deaton and Winbrake, 1999	X	X	X				
Espejo 1994	X	X					X
Forrester 1994	X						
Kali, Orion and Eylon 2003	X	X				X	X
Kasperidus, Langerfelder, and Biber 2006			X	X		X	
Maani and Maharaj 2002	X	X	X			X	X
Maani and Maharaj	X	X	X			X	X

2004							
Meadows 1991	X	X	X	X	X		
Ossimitz 2000	X	X	X				X
Potash and Heinbokel 1997			X	X		X	
Richmond 1991	X	X	X			X	
Richmond 1993	X	X	X	X	X	X	X
Richmond 1994	X	X	X	X	X		
Richmond 1997	X	X	X			X	X
Stuntz, Lyneis, and Richardson 2001	X	X	X			X	X
Sweeney and Sterman 2000		X	X	X		X	

Systems Thinking Continuum

Figure 2 presents the key components from Table 2 arranged as a continuum of systems thinking knowledge and skills.

Figure 2: Systems Thinking Continuum



Development of Systems Thinking Hierarchy using Bloom's Taxonomy

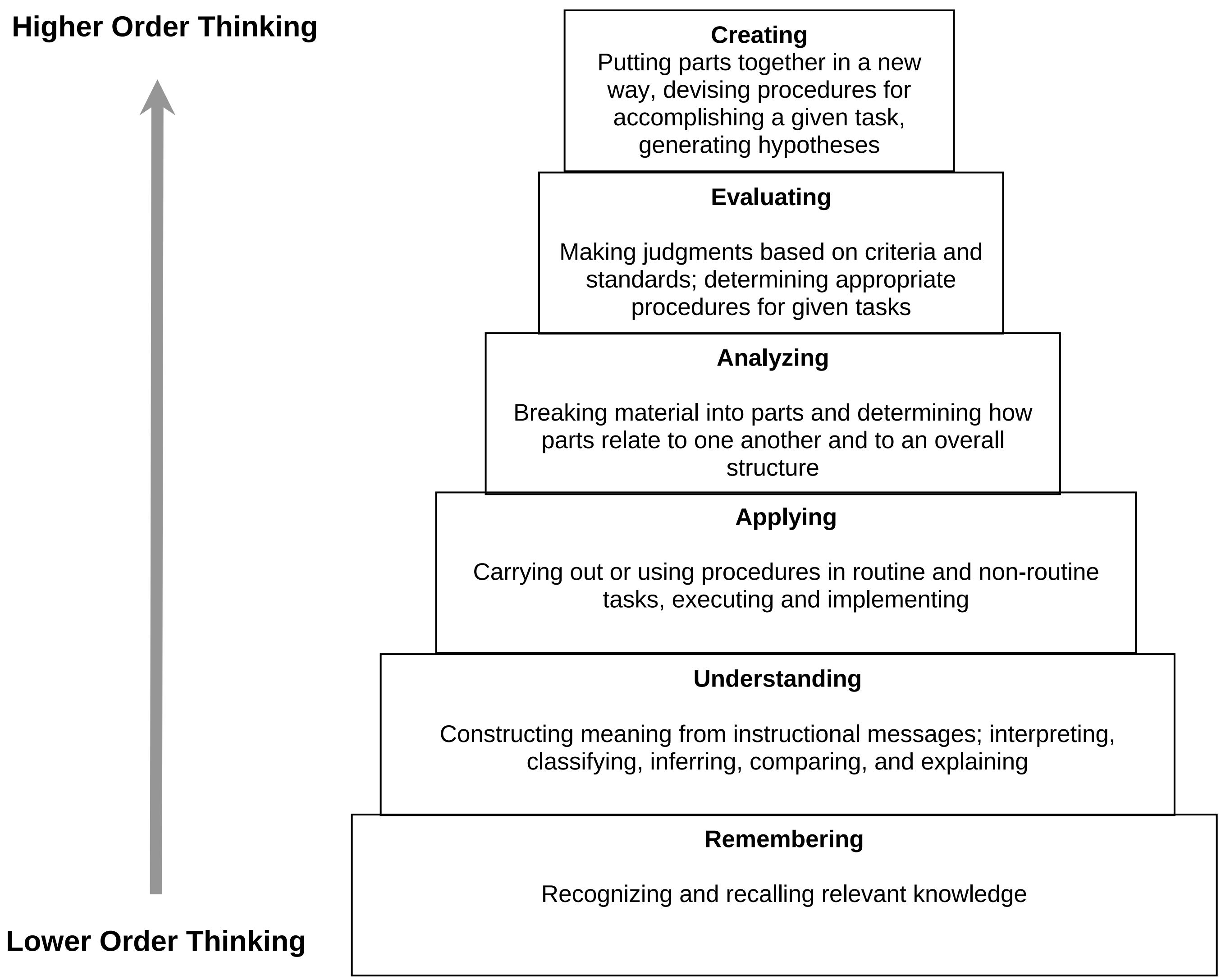
We turned to Bloom et al.'s (1956) *Taxonomy of Educational Objectives* for guidance on developing an assessment framework. Bloom and his colleagues proposed their taxonomy as a common framework for classifying student learning outcomes as well as promoting exchange of test items, testing procedures, and ideas about testing (Anderson and Krathwohl, 2001). Bloom felt that the framework should be adapted for different disciplines:

> "Ideally each major field should have its own taxonomy of objectives in its own language – more detailed, closer to the special language and thinking of its experts, reflecting its own appropriate sub-divisions and levels of education, with possible new categories, combinations of categories, and omitting categories as appropriate" (Bloom circa 1971, cited in Anderson and Krathwohl, 2001: xxvii-xxviii).

Following Bloom's directive, we propose a Taxonomy of Systems Thinking Characteristics and derive an assessment framework specific to this taxonomy.

Bloom's original framework was revised by Anderson and Krathwohl (2001) to reflect research outcomes since the publication of the 1956 framework. The revised taxonomy of educational objectives is shown in Figure 3, and is described in Anderson and Krathwohl (2001:66-88). Along with the descriptions of learning objectives at each level, Anderson and Krathwohl suggest tests and other assessment measures.

Figure 3. Bloom's Revised Taxonomy. (from Anderson and Krathwohl, 2001)



At the base of the revised taxonomy is the cognitive process of ***Remembering***. This category includes recognizing and recalling information. It is considered the most basic level of educational objective, in which the learner retrieves information from memory in the form in which it was presented.

The second level of Bloom's revised taxonomy is ***Understanding***, defined as being able to construct meaning from instruction. Objectives for learning at this level include the ability to interpret, exemplify, classify, summarize, infer, compare, and explain information. Interpreting is the process of converting information from one form to another. Exemplifying involves giving specific examples for general concepts or principles. Classifying is recognizing that something belongs to a specific category. Inferring is the process of finding a pattern within a series of examples or instances. Comparing involves identifying similarities and differences between two or more objects, events, ideas, problems, or situations. Explaining means understanding cause-effect relationships, or being able to explain how a change in one part of the system will affect another part of the system.

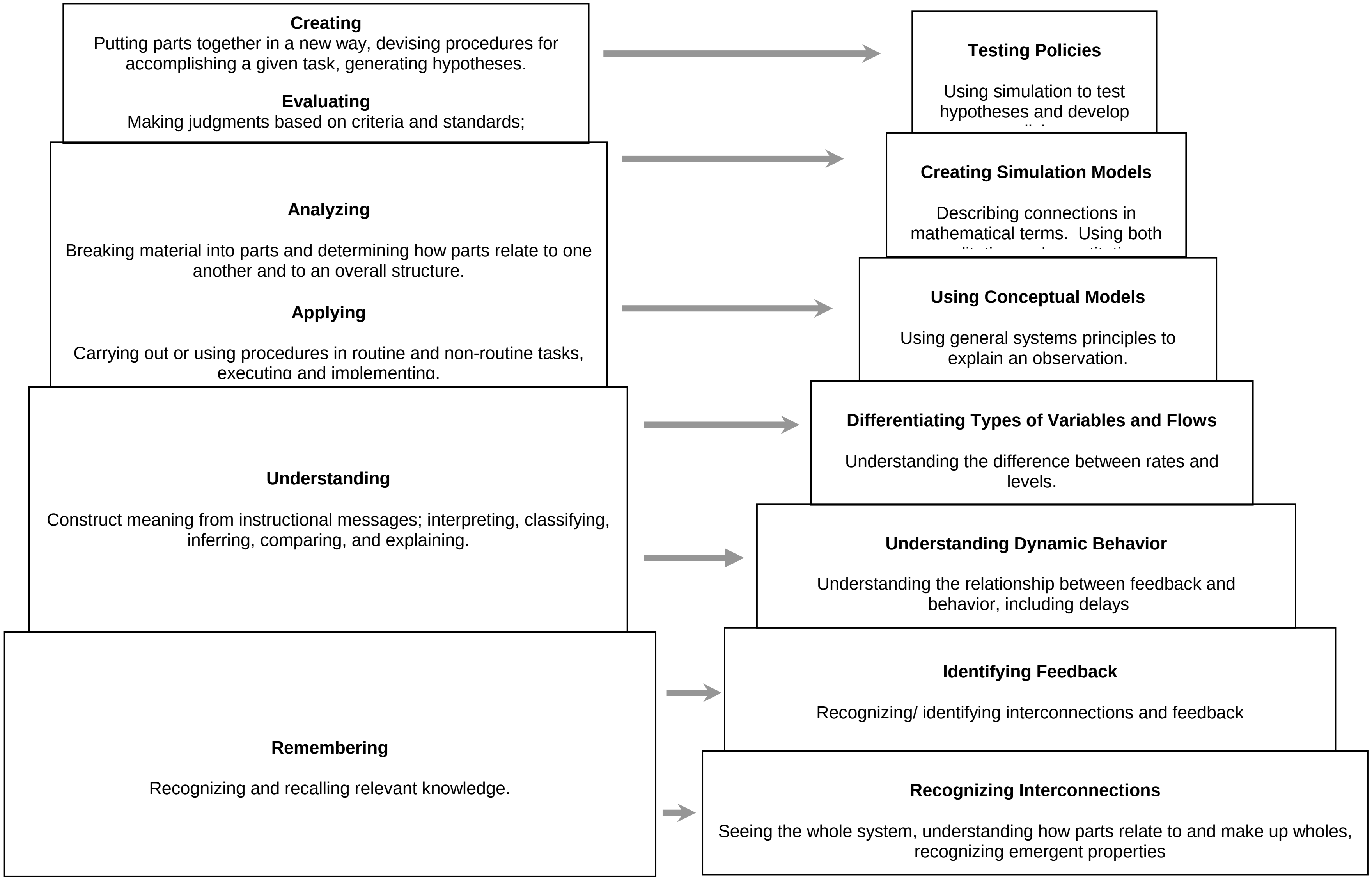
At the next level of educational objectives, ***Applying*** , a learner is expected to be able to use a previously learned procedure in familiar situations (executing a procedure) and unfamiliar situations (implementing). ***Analyzing*** is defined as the process of breaking down material to its constituent parts and finding how the parts relate to one another and the structure as a whole. Analyzing includes differentiating, organizing, and attributing, where differentiating is the process of distinguishing relevant and irrelevant information, and organizing is the process of identifying the parts of a systems and recognizing how these parts fit together to form a whole.

The highest levels of Bloom's revised taxonomy are ***Evaluating*** and ***Creating.*** Evaluation requires making judgments based on criteria and standards and includes checking for internal inconsistencies within a system. Creating is the process of putting parts together to form a whole. Creating includes generating alternative solutions to a problem that meet certain criteria, planning, or developing a solution method that meets the criteria of the problem, and finally, producing a plan for solving a problem.

Mapping Bloom's Taxonomy onto Systems Thinking

We compared the seven key components and the continuum derived from the literature to the levels of learning objectives in Bloom's taxonomy to create our proposed taxonomy of systems thinking characteristics. Figure 4 shows the relationship between the two sets of concepts. For the purposes of developing assessment measures, we felt that several of the systems thinking categories could be classified in the same level of Bloom's taxonomy. For example, we felt

Figure 4: Bloom's Revised Taxonomy Mapped onto Systems Thinking Characteristics



that Recognizing Interconnections and Identifying Feedback were both at the basic level of learning objectives, with one building on the other. It could also be argued that both of these components should be considered as part of Bloom's level of Understanding in that they require learners not simply to recall the definitions of systems, emergent properties, causality, and feedback, but also to identify examples of the concepts or classify system components using those concepts. For this initial taxonomy, however, we consider recognizing interconnections and identifying feedback as the basic level of systems thinking because they require the simplest tasks of identifying relationships from presented material.

We felt that both Understanding Dynamic Behavior and Differentiating Types of Variables and Flows fell under Bloom's category of ***Understanding***. To achieve these levels of the taxonomy, learners need to be able to not only recognize feedback, but also understand how structure generates behavior.

The next two systems thinking components, Using Conceptual Models and Creating Simulation Models seem to correspond to both the ***Applying*** and ***Analyzing*** levels in Bloom's framework. It is not clear whether the ability to create a simulation model is a higher order of systems thinking than being able to use general principles to explain an observation or vice versa. In any case, both of these components require the ability to synthesize individual systems concepts and apply them to unfamiliar situations.

The top two levels, the highest orders of thinking in Bloom's taxonomy are ***Evaluating*** and ***Creating***. We felt that the development and use of simulation models to test hypotheses spanned both of Bloom's top levels. Testing policies involves identifying places to intervene within a system, hypothesizing the effect of changes, interpreting model output with respect to a problem, and designing policies based on model analysis. Testing policies requires the ability to construct and validate a model, discover leverage points, and compare solutions from those leverage points.

Based on the resulting Taxonomy of Systems Thinking Objectives, we developed an initial set of assessment measures, shown in Table 3. We see this as a preliminary list, to stimulate discussion and further development of an assessment measures. We invite comments and suggestions for improving and expanding the definition of the taxonomy and the assessment measures.

TABLE 3. Proposed Assessment Measures by Level of Systems Thinking

Systems Thinking Levels	**Indicators of Achievement** **A person thinking at this level should be able to:**	**Products, Assessment Tests**
Recognizing Interconnections	- Identify parts of a system - Identify causal connections among parts - Recognize that the system is made up of the parts and their connections - Recognize emergent properties of the system	- List of systems parts - Connections represented in words or diagrams - Description of the systems in terms of its parts and connections - Definition of emergent properties - Description of properties the system has that the components alone do not
Identifying Feedback	- Recognize chains of causal links - Identify closed loops - Describe polarity of a link - Determine the polarity of a loop	- Representation of causality and loops in words or diagrams - Diagram indicating polarity
Understanding Dynamic Behavior	- Describe problems in terms of behavior over time - Understand that behavior is a function of structure - Explain the behavior of a particular causal relationship or feedback loop - Explain the behavior of linked feedback loops - Explain the effect of delays - Infer basic structure from behavior	- Representation of a problematic trend in words or graphs - Story of how problematic behavior arises from interactions among system components - Story about what will happen when one piece of the system changes - Story of the causal structure likely generating a given behavior
Differentiating types of variables and flows	- Classify parts of the system according to their functions - Distinguish accumulations from rates - Distinguish material from information flows - Identify units of measure for variables and flows	- Table of system variables by type - Types of variables with units

Using conceptual models	- Use a conceptual model of system structure to suggest potential solutions to a problem	- Story of the expected effect of an action on a given problem - Justification of why a given action is expected to solve a problem
Creating simulation models	- Represent relationships between variables in mathematical terms - Build a functioning model - Operate the model - Validate the model	- Model equations - Simulation model - Model run - Compare model output to observed behavior
Testing policies	- Identify places to intervene within the system - Hypothesize the effect of changes - Use model to test the effect of changes - Interpret model output with respect to problem - Design policies based on model analysis	- List of policy levers - Description of expected output for given change - Model output - Comparison of output from different hypothesis tests - Policy design

Feedback from 2007 System Dynamics Conference

We received many good comments and suggestions from the presentation of these ideas at the 2007 International System Dynamics Conference in Boston, Massachusetts. Comments from conference attendees included the following:

- Recognizing interconnections is too simple. This is a step that everyone already does, so it does not need to be included in the taxonomy.
- Testing policies should come before understanding dynamic behavior, instead of being the final step. The only way to understand how the structure is affecting the behavior is to run a model and test different policies using the model. Running a model is much easier that identifying how structure affects behavior.
- Is the systems thinking continuum really a continuum, or is fuzzier than that? Should this continuum include multidimensional space?
- Mental models are validated by experience.
- It is possible to simply skip from recognizing interconnections to creating simulation models. For example, with superstitions, people do not go

through the other steps within the continuum. They recognize a situation as fitting the superstition and then move to making conclusions.

- Do you move from recognizing parts of a system to the whole system (induction) or understanding the whole system and then the parts that make up that system (deduction)?
- The order of the continuum may be connected to learning styles. Depending on how people learn, they may follow the steps in a different way. The continuum may not be so linear.
- Being able to reframe system boundaries or choose appropriate system boundaries is important in solving problems.
- Being able to recognize interconnections can be the hardest task.
- The effort to measure a person's level of systems thinking might bias the measurement.

This feedback suggests several interesting directions for further development of the taxonomy, including how learning styles might affect the development of systems thinking characteristics and what other dimensions of learning might be important to incorporate into the framework. We are currently using this proposed framework to examine the systems interventions that have been reported in the literature.

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