Assessing the Effectiveness of Systems Thinking Interventions in the Classroom

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Abstract

This paper presents an analysis of systems thinking interventions in educational settings. Although these interventions have been implemented in K-12 classrooms since the mid 1980s, there is still no clear definition of systems thinking or identification of the best method to test the effectiveness of interventions or methods for teaching systems thinking The goal of this paper is to answer the question: how can we best assess the effectiveness of systems thinking interventions in education? This question begs three sub questions: (1) what is systems thinking, (2) what systems thinking interventions are being used in education, and (3) how have the effect of interventions been measured? The purpose of answering these questions was to propose methods for assessing systems thinking interventions. The analysis of systems thinking interventions in the classroom yielded an initial set of guidelines for measuring and raising a person's level of systems thinking.

Keywords: systems thinking, K-12 education, assessment measures

Introduction

Systems thinking interventions, that is, teaching methods that promote systems thinking skills or abilities, have been implemented in schools for at least 20 years. Researchers have also tested the effect of systems thinking teaching on students' critical thinking and decision-making skills. Still, there is no clear definition of systems thinking or identification of the best methods for teaching or testing the effectiveness of systems thinking (ST) interventions. The goal of this

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paper is to begin the development of a set of best practices for assessing the effectiveness of systems thinking interventions in education. It first addresses three sub questions: (1) what is systems thinking, (2) what systems thinking interventions are being used in education, and (3) how have the effects of interventions been measured to date?

Systems Thinking Interventions in the Classroom

Most of the reports we have about the effectiveness of systems thinking interventions describe qualitative observations by teachers in the classroom. Advocates of systems-based teaching (e.g., Richmond 1990) say that traditional, lecture-format teaching, results in students passively receiving and memorizing large quantities of fragmented information. They believe the systems approach is integrative, promotes active learning, and helps students develop critical thinking and problem solving skills (e.g., Grant 1998, Lyneis and Fox-Melanson, 2001). Grant (1998: 70) argues that the systems approach presents a "common conceptual framework and vocabulary" that is necessary to "develop an integrated educational program." Research has shown that active learning creates a longer lasting understanding of scientific concepts, skills, and the nature of science (Leonard, Speziale, and Penick, 2001). Stuntz, Lyneis, and Richardson (2002: 4) argue that a systems perspective helps students better understand interdependencies, long and short-term decisions, and consequences of their own actions within a system. In spite of the positive nature of such observations, however, many teachers and researchers note the need for more rigorous analysis (Costello, 2001, Hight, 1995, Maani and Maharaj, 2002, and Sweeney and Sterman, 2000).

Methods

Search Procedures

The first step of this study was a comprehensive review of the literature to identify studies about systems thinking in general, systems thinking definitions, and systems thinking interventions performed in kindergarten through post-graduate classrooms. The literature review included all published studies, unpublished studies, theses and dissertations, and papers presented at conferences on the subject from 1980, the beginning of systems thinking interventions in K-12 classrooms to September, 2007.

Search procedures included the search of electronic databases, including Academic Search Premier, Dissertations and Theses, Education Full Text, ERIC, Science Direct, Scopus, and the 2007 System Dynamics Bibliography. Descriptors that were used in the searches included education, interventions, systems, system dynamics, and systems thinking. System dynamics was used as a descriptor because in the field of system dynamics, many researchers do not make a distinction between systems thinking and system dynamics. Table 1 shows the number of papers returned using each descriptor for each database. The System Dynamics Bibliography includes articles from journals, the International System Dynamics Conference, dissertations and theses, and books that are specifically reported by the System Dynamics Society. The bibliography contains over 7,800 references and is updated every six months (System Dynamics Bibliography, 2007). An ancestry search of each reference list was also used in order to identify relevant research that was cited by authors of research that was identified.

Table 1: Number of hits per keyword for each database

Science Direct					
	Systems Thinking	Education	Systems	Intervention	System Dynamics
Systems Thinking	1,242	95	1,242	42	67
Education	95	-	79	3,924	79
Systems	1,242	5,268	-	7,776	29,380
Intervention	42	3,924	7,776	-	162
System Dynamics	67	79	29,380	162	29,380
Academic Search Premier					
	Systems Thinking	Education	Systems	Intervention	System Dynamics
Systems Thinking	296	73	296	16	10
Education	73	-	28,888	16,392	42
Systems	296	28,888	-	5,752	1,963
Intervention	16	16,392	5,752	-	16
System Dynamics	10	42	1,963	16	1,963
Dissertation and Theses					
	Systems Thinking	Education	Systems	Intervention	System Dynamics

Systems Thinking	365	40	365	30	17
Education	153	-	35,234	14,505	40
Systems	365	35,234	-	7,540	1,256
Intervention	30	14,505	7,540	-	27
System Dynamics	17	40	1,256	27	1,256
Education Full Text					
	Systems Thinking	Education	Systems	Intervention	System Dynamics
Systems Thinking	955	633	955	15	33
Education	633	-	26,978	6,964	316
Systems	955	26,978	-	874	520
Intervention	15	6,964	874	-	19
System Dynamics	33	316	520	19	520
ERIC					
	Systems Thinking	Education	Systems	Intervention	System Dynamics
Systems Thinking	218	166	218	8	5
Education	166	-	43,392	23,403	65
Systems	218	43,392	-	2,949	65
Intervention	8	23,403	2,949	-	6
System Dynamics	5	65	65	6	65
SCOPUS					
	Systems Thinking	Education	Systems	Intervention	System Dynamics
Systems Thinking	11,725	1,513	11,725	417	503
Education	1,513	-	108,141	38,537	2,212
Systems	11,725	108,141	-	64,282	194,412
Intervention	417	38,537	64,282	-	1,293
System Dynamics	503	2,212	194,412	1,293	194,412

The Creative Learning Exchange (CLE) website (clexchange.org) contains a library of materials about systems thinking in general and systems thinking interventions within K-12 classrooms. We also searched the CLE library using the term systems thinking. A search within the *System Dynamics Review* and the *Systems Thinker* was performed to identify articles that may have been overlooked in the database search. Finally, after it was established that the majority of researchers writing about systems thinking were system dynamicists, materials were solicited from systems thinking and system dynamics professionals using the K-12 Listserve operated by the Creative Learning Exchange, the 2006 Systems Thinking and Dynamic Modeling for K-12 Conference, in Marlboro, Massachusetts, and the 2007 International System Dynamics Conference in Boston, Massachusetts. All of the suggestions provided by systems thinking professionals were researched. In all, over two hundred papers and books were examined to identify the pool of information that represents the current knowledge about systems thinking and systems thinking interventions in the field of education.

What is SystemsThinking?

The second step was to examine the use of the term "systems thinking" for some consensus about the definition. We started with a limited review of the literature and plus interviews with systems educators at the 2006 Systems Thinking and Dynamic Modeling for K-12 Conference. From this research, we found a range of views about the definition of systems thinking and how educators are measuring systems thinking characteristics. An in-depth discussion of this step was published in Stave and Hopper (2007). Based on this initial research, we performed a more comprehensive review of the literature, as described above, and used Bloom's Taxonomy in order to develop the Taxonomy of Systems Thinking Characteristics, shown in Figure 2 (Stave and Hopper, 2007).

The Proposed Taxonomy of Systems Thinking Characteristics includes the following key levels (see Stave and Hopper, 2007):

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.

2. Identifying Feedback

This characteristic includes the ability to identify cause-effect relationships between parts of a system, describe chains of causal relationships, recognize

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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.

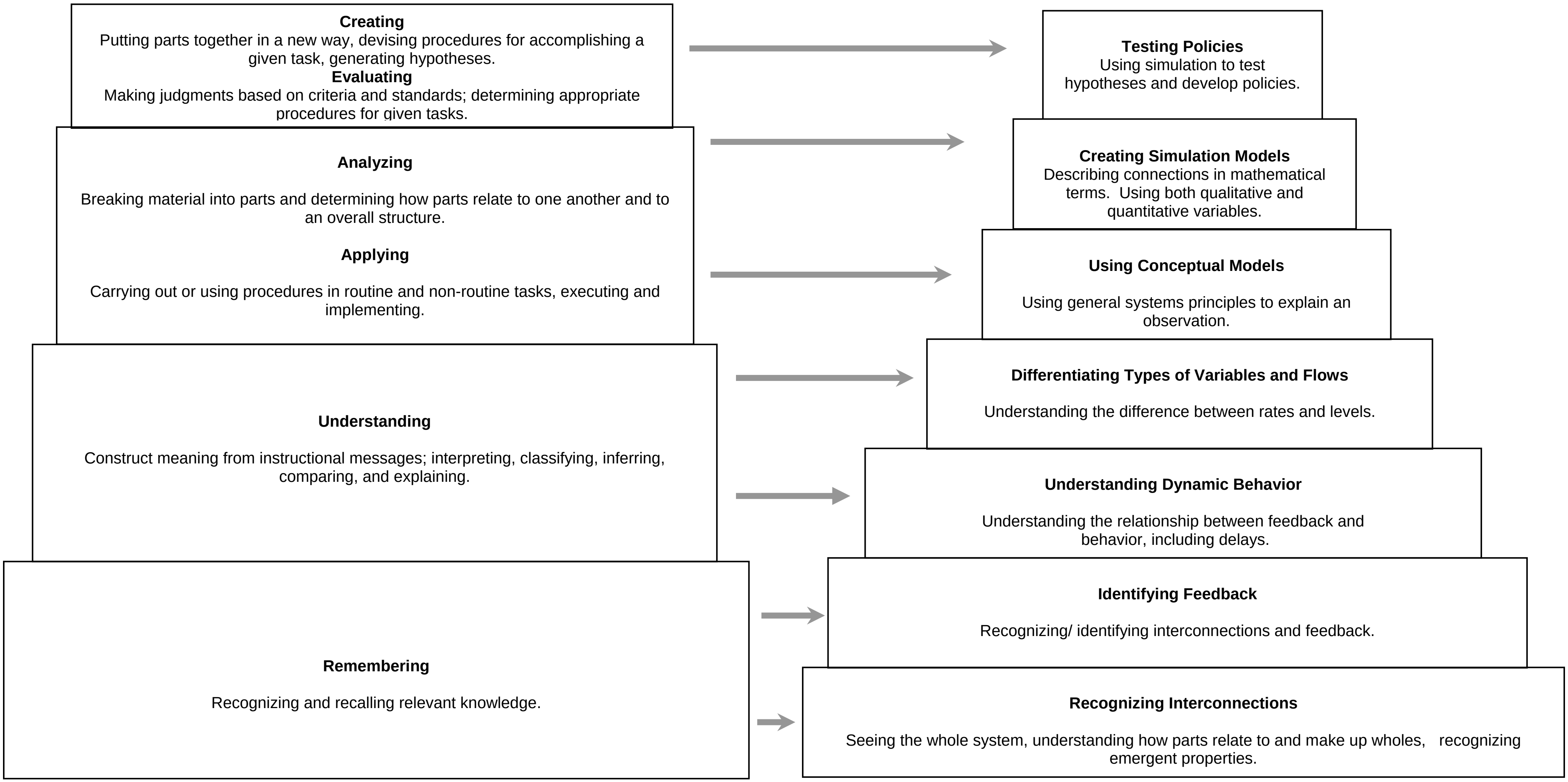
5. Using Conceptual Models
Being able to explain system behavior requires the ability to synthesize and apply the concepts of causality, feedback, and types of variables.

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.

We used these seven common characteristics, together with Bloom et al.'s (1956) *Taxonomy of Educational Objectives* as a starting point to develop an assessment framework for systems thinking interventions.

Figure 2. Bloom's Revised Taxonomy Mapped onto Systems Thinking Characteristics



Systems Thinking Interventions

To identify what systems thinking interventions are being used in education and how the effects of interventions have been measured, we went back our pool of papers from the initial literature review. The goal was to find any reports of scientific studies on systems thinking interventions in kindergarten through post-graduate education. The literature identified through the methods previously described was reviewed a second time in order to identify interventions that used the scientific method. In order to analyze this research, we: (1) identified papers describing scientific studies from the literature review, (2) evaluated the systems literature through a meta-synthesis in order to make conclusions about the effectiveness of systems thinking interventions, and (3) proposed methods for assessing systems thinking interventions that correspond with the application of Bloom's Taxonomy.

Selection Criteria

Studies that used an intervention in kindergarten to post-graduate classrooms to measure or raise a person's level of systems thinking were considered relevant for inclusion in this paper, but only papers with a specific research question were included in the following meta-synthesis. Papers published on classroom lessons that did not describe a specific research protocol were not included, although some were described in the introduction to this paper.

Data Analysis

From the initial pool of 200 papers, we selected a subset of papers using the following criteria: the research (1) had a specific research question, (2) used a version of the scientific method, (3) tested a systems thinking intervention in a classroom at the kindergarten through post-graduate level, and (4) tested the effectiveness of the intervention in measuring or raising a person's level of systems thinking. Of the 200 papers and books researched, only fourteen papers met the criteria.

Meta-Synthesis

Table 4 summarizes the information collected from these papers. Eight of the fourteen studies used one or several of the systems thinking inventory tasks, bathtub, cash flow, or manufacturing tasks that were created in 2000 by Sweeney and Sterman. Sweeney and Sterman (2000; 250) list skills such as understanding how behavior is a function of the system, understanding and representing feedback, identifying stocks and flows, recognizing delays, identifying nonlinearities, and identifying and testing the boundaries of models in their definition of systems thinking.

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Table 4: Meta-Synthesis Research Coded in Specific Categories

Back-ground	Classroom Characteristics				Intervention Characteristics			
Authors	Grades	Teaching Subjects	# of Subjects	ST or SD Experience	Type of Intervention	Description of Intervention	Research Method	ST Skill Tested
A1	Eighth	Earth Science	50	None	Laboratory and outdoor learning inquiry-based activities.	Students completed a 45-hour course on the hydro cycle.	7 types of assessment: (1) Questionnaires, (2) drawing analysis, (3) word association, (4) concept maps, (5)Interviews, (6) Repertory grid, and (7) Observations.	**Recognizing Interconnections -** Questionnaire, drawing analysis, word association, concept maps, interviews, and repertory grid were developed to measure students' ability to identify relationships among concepts and their understanding of the dynamics of groundwater. **Identifying Feedback -** Questionnaire, drawing analysis, and concept maps tested students' ability to understand the cyclic system. **Understanding Dynamic Behavior -** Repertory grid asks students to understand hidden dimensions. **Using Conceptual Models** - Drawing analysis and concept maps.
C1	Undergraduate Students	System Dynamics/Systems Thinking	50	Readings about systems thinking, lectures on the application of systems thinking tools, and instruction on causal loop diagramming, behavior over time graphs, structure-behavior	Lecture and microworld	Students were lectured on five systems thinking tools (causal loop diagramming, behavior over time graphs, structure-behavior assumptions, surfacing assumptions, and causal tracing) and then asked to	Microworld	**Testing Policies -** Students made decisions about the business that they were running through the simulation.

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				assumptions, surfacing assumptions, and causal tracing.		use a microworld.		
D1	Graduate Students	Business	31	Taught ST in between pre and posttest.	Lectures and tests - students had to participate in study in order to fulfill course requirements. Individual learning in lecture hall or computer lab.	Students given case 1 week prior to pretest, taught ST between pretest and posttest 1, and taught SD modeling between posttest 1 and 2.	Case Study. Pretest/Posttest - 1 Pretest and 2 Posttests.	**Understanding Dynamic Behavior** - Scenario of a consulting and IT firm. Scenario described periodic oscillations in revenue over time. Participants were asked to analyze the situation and assess the causes of the periodic oscillations. **Differentiating Types of Variables** - Students asked to discern between stock and flows. **Create Simulation Model -** Participants asked to model scenario and perform sensitivity analysis. **Testing Policies -** Participants asked to advise a long-term solution to the problem.

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D2	College Seniors and post-baccalaureate students	Advanced Accounting	81	None	Lectures, problems, and case studies.	Students given practice set and had to formulate acquisition date journal entries. Worked with income statement, retained earning, balance sheet, and intercompany transactions. Students had to integrate new knowledge with the existing knowledge.	Exams	**Understanding Dynamic Behavior -** Students asked to work through problem sets with variables dependent on each other.
F1	10th to 12th	Advanced Algebra and AP Calculus	91	30 of the AP calculus students used system dynamics modeling and analysis of flow and accumulation graphs are part of the calculus curriculum.	In class task.	Bathtub Task and Cash Flow Task	Assessment	**Differentiating Types of Variables –** Bathtub and Cash Flow Tasks

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G1	First year MBA students	General Management Course	70	None	Case Study in class.	Case material focused on Goodyear. Case focused on the long term dynamics of the business and the consequences of investing different businesses.	Classroom observation.	**Identifying Feedback -** Instructors develop a conceptual feedback model that fit both the storyline and factual detail of the case. **Testing Policies -** Students framed case issues and recommendations in terms of feedback processes and business dynamics.
H1	7th to 10th	Social Science Courses	39	BOTGs	In class task.	Bathtub Task given to students as either a worksheet or a quiz.	Assessment	**Differentiating Types of Variables –** Bath Tub
K1	Undergraduate	Business administration students taking Applied Statistics	64	1.5 hour lecture introducing stocks and flows after pretest.	In class task.	Students given several tasks: (1) Water butt flow, (2) Tabular Hospital, (3) Graphic Parking Lot, (4) Surge Tank, and (5) Maier's bathtub stock.	Pretest/Posttest with 1.5 hour lecture introducing stock-flow concepts between tests.	**Differentiating Types of Variables** - All tasks assess whether students could differentiate and work with stocks and flows.
K2	Seventh	Earth Science	40	None	Lectures, activities, and field trip	Students given inquiry activities, diagramming activities, a field trip, and a knowledge integration activity that required construction of different rock processes.	Pretest after first three activities, knowledge integration activity, then posttest.	**Recognizing Interconnections -** Understanding the rock cycle was considered to be the ability to construct causal relationships in a process.

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K3	Tenth grade, Undergraduate and Graduate Students	Forest science and Sustainable Resource Management (SRM)	54	SRM students had covered a systems thinking lecture prior to the assessment.	In class task.	Department store, Bathtub task, and Manufacturing Case Task.	Assessment	**Understanding Dynamic Behavior -** Manufacturing Task **Differentiating Types of Variables -** Department Store Task and Bathtub Task
O1	Undergraduate and Graduate Students	3 Classes: Business Administration, Environmental Systems, and Departments not specified	154	None	In class task.	6 Tasks: (1) Federal Deficit vs. National Debt, (2) Arrivals and departures in the Alpenhotel, (3) Bathtub Task 1, (4) Bathtub Task 2, (5) Filling of an Oil tank, and (6) Filling and emptying of a Bathtub	Assessment	**Differentiating Types of Variables**: All tasks tested students' ability to differentiate between stocks and flows.
P1	Undergraduate Students	Research design course and Introductory System Dynamics Course	70	Posttest after the last day of the system dynamics course.	In class task.	Department store, manufacturing, and CO2 tasks.	Pretest/Posttest	**Understanding Dynamic Behavior -** Manufacturing Task **Differentiating Types of Variables -** Department Store Task and CO2 Task
S1	Undergraduate and Graduate Students	Introductory SD class	518	1/2 students had played the beer game.	In class task.	Bathtub, cash flow, and manufacturing task.	Assessment	**Understanding Dynamic Behavior** - Manufacturing Task **Differentiating Types of Variables** - Bathtub and cash flow.

Z1	High School Students	SYMFEST participants who had taken a class that taught SD modeling or used models.	82	Ranged from one semester where they used but did not build models in a course, to five years of instruction in modeling.	Assessment	Bathtub and Cash Flow	Assessment	**Understanding Dynamic Behavior** - Manufacturing Task **Differentiating Types of Variables -** Bath tub and cash flow.

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These skills were placed in the categories of identifying feedback, understanding dynamic behavior, differentiating types of flows and variables, and creating simulation models based on the taxonomy of systems thinkers described by Stave and Hopper (2007). The tests that Sweeney and Sterman (2000; 252) created were established to "explore students' baseline systems thinking abilities." With each of the tasks, students were given a short paragraph describing a situation and were then asked to draw the expected behavior over time on a graph (Sweeney and Sterman, 2000; 252). The bathtub and cash flow tasks ask students to determine how the quantity of a stock changes over time given the rates of inflows and outflows. The manufacturing task requires students to draw the behavior of a stock given a time delay and negative feedback loop.

Although Sweeney and Sterman (2000) list several characteristics of systems thinkers, they are only testing students' ability to understand dynamic behavior and differentiate types of variables. These tests are very specialized and do not test all of the characteristics of a systems thinker. Table 5 shows the assessment measures suggested by Stave and Hopper (2007) compared to Sweeney and Sterman's (2000). Since the majority of researchers use Sweeney and Sterman's (2000) inventory tasks for testing a student's level of systems thinking, we cannot measure a person's level of systems thinking if they are in the lower levels of the taxonomy or if they are above differentiating variables.

Table 5: Stave and Hopper's (2007) Proposed Assessment Measures by Level of Systems Thinking Compared to Sweeney and Sterman's (2000)

Systems Thinking Levels	Products, Assessment Tests	Systems Thinking Inventory Tasks Described by Sweeney and Sterman (2000)
Recognizing Interconnections	- 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	- Representation of causality and loops in words or diagrams - Diagram indicating polarity	

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Understanding Dynamic 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	- Manufacturing Task (Asks students to determine a trend in the presence of a delay and negative feedback.
Differentiating types of variables and flows	- Table of system variables by type - Types of variables with units	- Bathtub and Cash Flow Tasks (Ask students to determine how the quantity of a stock changes based on its flow.)
Using conceptual models	- 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	- Model equations - Simulation model - Model run - Compare model output to observed behavior	
Testing policies	- List of policy levers - Description of expected output for given change - Model output - Comparison of output from different hypothesis tests - Policy design	

Systems Thinking Skills Tested: The systems thinking skills tested by each author are shown in Table 6. The majority of the researchers in this table tested students' understanding of dynamic behavior and their ability to differentiate types of variables and flows. These skills are both at the intermediate level of the taxonomy based on Stave and Hopper's (2007) taxonomy of systems thinking characteristics. Few researchers tested the lower or higher levels of the systems thinking taxonomy.

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Table 6: Systems Thinking Characteristics Tested by Systems Thinking Interventions

ST Characteristic	Recognizing Interconnections	Identifying Feedback	Understanding Dynamic Behavior	Differentiating Types of Variables and Flows	Using Conceptual Models	Creating Simulation Models	Testing Policies
Author							
A1	X	X	X		X		
C1							X
D1			X	X		X	X
D2			X				
F1				X			
G1		X					X
H1				X			
K1				X			
K2	X						
K3			X	X			
O1				X			
P1			X	X			
S1			X	X			
Z1			X	X			

Table 7 shows the number of different types of assessments that the researchers used to test systems thinking characteristics. The level that the majority of researchers assessed, differentiating types of flows and variables has only one type of assessment. Sweeney and Sterman (2000) proposed several different systems thinking inventory tasks, bathtub flow, cash flow, and manufacturing tasks; however, these tasks all measure the same ability. Each of the tests shown in Table 7 for the category differentiating types of flows and variables test students' ability to calculate a stock based on changing flows. Although these tasks do assess whether students can differentiate between stocks and flows, there are other ways that students could be tested, as shown in Table 3.

Table 7: Type of Assessment Used to Test Systems Thinking Characteristics

Recognizing Inter-Connections	**Identifying Feedback**	**Understanding Dynamic Behavior**	**Differentiating Types of Flows and Variables**	**Using Conceptual Models**	**Creating Simulation Models**	**Testing Policies**
6	2	3	1	2	1	2

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Table 8 shows the results from the fourteen studies synthesized in this paper. The horizontal axis of this table represents how well students performed within each study. If students' level of systems thinking did not change, the study was classified as low in the table. A study was classified as high if the majority of the students showed an increase in their level of systems thinking. Studies with the lowest results used isolated exercises, whereas researchers found that a greater majority of students' systems thinking level was raised when students had more experience with systems thinking.

Table 8: Results Reported by Study Authors

ST Intervention	**Low**	**Medium**	**High**
Isolated Exercise w/o ST Experience	2		
Isolated Exercise w/ ST Experience	2		3
Lecture within a Course w/o ST Experience			
Lecture within a Course w/ ST Experience		1	1
Unit within a Course w/o ST Experience		2	1
Unit within a Course w/ ST Experience		1	1

Discussion

The data from the fourteen studies suggests the following:

1. There is strong support for higher order skills being built upon the lower order skills.

A hierarchical view of how students learn is supported by both the educational literature and the assessments that I reviewed for this paper. Bloom et al. (1984; 16) argue that:

> So long as the simpler behaviors may be viewed as components of the more complex behaviors, we can view the educational process as one of building on the simpler behavior. Thus, a particular behavior which is classified in one way at a given time may develop and become integrated with other behaviors to form a more complex behavior which is classified in a different way.

Researchers who tested students' systems thinking ability from the lower systems thinking skills to higher found that these students performed better on assessments than students tested only on the higher order skills. Also, students that had previous experience with systems thinking or system dynamics performed better on the assessments than students that did not. Students need a foundation on which to build in order to increase in their systems thinking abilities.

2. The interventions that are reported on test the intermediate level on the systems thinking taxonomy, which suggests that the intermediate levels are being taught in the classroom.

Seven of the fourteen studies tested students' ability to understand dynamic behavior and nine of the fourteen studies tested students' ability to differentiate between types of variables and flows. Based on the reported interventions, it appears that students are being taught and tested primarily on these two levels the most. In order to establish what students being taught and if they are increasing their systems thinking ability, we need more information.

3. Half of the studies used the assessment framework developed by Sweeney and Sterman (2000), which is only appropriate for measuring certain levels of the systems thinking taxonomy. Based on this finding, we need to develop other ways in which to assess students' systems thinking ability.

As Table 5 shows, the most developed assessment measures are for differentiating types of flows and variables. Although these are useful tests for this specific level, more tests need to be developed for each of the other levels. It is not possible to assess where a student falls on the systems thinking continuum if we can only successfully test their ability to differentiate between types of flows and variables. It is also not possible to assess the effectiveness of these interventions if only a handful of researchers have tested each level of the systems thinking taxonomy.

Assessing Systems Thinking Interventions

After analyzing systems thinking interventions in the classroom, we revised the table of proposed assessment measures initially proposed in Stave and Hopper (2007) as shown below in Table 9. The purpose of this table is to clarify what students should demonstrate if they have completed a level and how we should measure their ability. The products, assessment tests column was added to for each systems thinking level, based on the fourteen studies analyzed for this paper.

Table 9: Revision of the Proposed Assessment Measures by Level of Systems Thinking

Systems Thinking Levels	Indicators of Achievement A person thinking at this level	Products, Assessment Tests

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	should be able to:	
Recognizing Interconnections	- Identify parts of a system - Identify causal connections among parts - Recognize that parts make up the whole system - Recognize that the system is made up of the parts and their connections - Recognize emergent properties of the system	- List of system parts - Connections between parts represented in words or diagrams (CONCEPT MAP) - Description of how the parts of the system make up the whole - Description of how the whole breaks down into parts - 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 (CAUSAL LOOP DIAGRAM) - 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 - Description of how problematic behavior arises from interactions among system components - Description or representation of what will happen when one piece of the system changes - Description of how the causal structure is generating a given Behavior - Representation in words or graph of how polarity affects the behavior of systems (MANUFACTURING TASK) - Representation in words or graph of the dynamic nature of systems
Differentiating types of variables and flows	- Classify parts of the system according to their functions - Distinguish accumulations from rates - Distinguish material from information flows	- Ability to move from a causal diagram to one that differentiates between the different types of variables - Table of system variables by type

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	- Identify units of measure for variables and flows	- Description of how and why the variables are different - Calculation of changing stock based on the flows (BATHTUB, CASH FLOW, and DEPARTMENT STORE TASKS) - Types of variables with units
Using conceptual models	- Use a conceptual model of system structure to suggest potential solutions to a problem	- Representation or description of the expected effect of an action on a given problem - Justification of why a given action is expected to solve a problem - Paper and pencil simulation of a dynamic system
Creating simulation models	- Represent relationships between variables in mathematical terms - Build a functioning model - Operate the model - Validate the model	- Ability to move from a paper and pencil simulation to a computer simulation - Creation of model equations - Simulation of a model - Running the model - 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 - Understand how to use model output to make real world recommendations	- List of policy levers - Description of expected output for given change - Comparison of model output from different hypothesis tests (MICROWORLD) - Policy design - Description of decisions made based on model output. - Recommended policies for the real world based on model output.

The purpose of this paper was to identify ways to measure a person's level of systems thinking and begin a discussion of how we might develop more rigorous ways of testing the effectiveness of systems thinking interventions. This is only an initial step. We hope it sparks further discussion and development of more sophisticated assessment measures.

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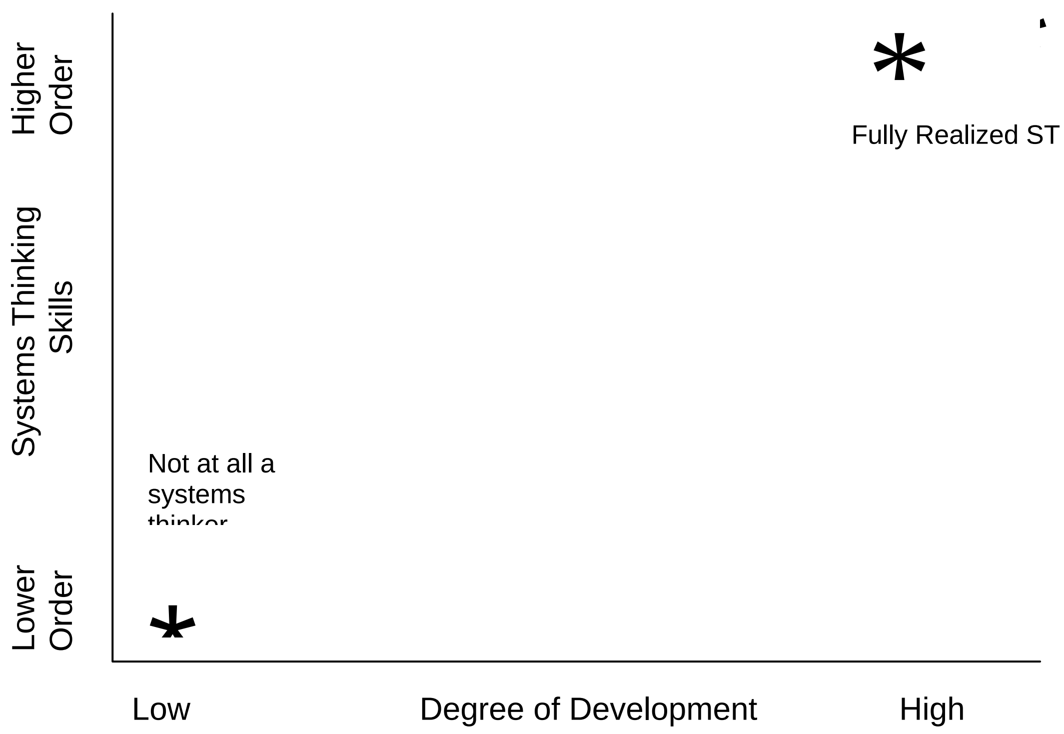
Two additional pathways for discussion have been suggested in response to our initial proposed taxonomy and continuum of system thinking skills. First, several people find the taxonomy and continuum too linear and one-dimensional. Second, non-system dynamicists suggest that creating simulation models may not be the only way to demonstrate the highest order of systems thinking

Regarding the one-dimensional nature of the proposed taxonomy, several people suggested that the continuum should be at least two-dimensional. Figure 3 shows one potential two-dimensional version of a systems thinking continuum. The Y-axis still shows the hierarchy proposed in the taxonomy, but the X-axis allows the representation of the level of development of the skills, from low to high. In this representation, a person could be low on the continuum of systems thinking skills, but highly developed within that skill, or a person could be high on the continuum of systems thinking skills, but have a low level of development within that skill. This two-dimensional scheme supports many non-linear pathways for developing systems thinking skills.

Figure 3: Two Dimensional Systems Thinking Continuum



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Regarding simulation, several non-system dynamicists suggested that the focus on simulation modeling might be too narrow. The system dynamics community believes that creating simulation models is at the top of the abilities for systems thinkers; however, this may not true for the entire systems thinking community. According to Anderson and Krathwohl (2001) students at the evaluation level should be able to: argue, critique, defend, interpret, judge, measure, test, and verify. Displaying these abilities does not require the creation of a system dynamics model. Students can use other means to display these qualities, so the top level of the systems thinking taxonomy can be achieved through different means according to a specific field. Students need to demonstrate that they can propose and evaluate hypotheses based on a framework.

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