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Proposing measures for assessing systems thinking interventions

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PROPOSING MEASURES FOR ASSESSING
SYSTEMS THINKING INTERVENTIONS

by

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Bachelor of Science
Cornell University
2005

A professional paper submitted in partial fulfillment
of the requirements for the

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Hank Greenspun Department of Environmental Studies
Greenspun College of Urban Affairs**

**Graduate College
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ABSTRACT

Proposing Methods for Assessing Systems Thinking Interventions

by

Megan Hopper

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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 do we assess the effectiveness of systems thinking interventions in education? In order to answer this question, I had to address the following 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. Through analysis of systems thinking interventions in the classroom, I derived guidelines for measuring and raising a person's level of systems thinking.

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CHAPTER 1

INTRODUCTION

Systems thinking interventions, which are teaching methods that promote systems thinking skills or abilities, have been implemented in schools for the past 20 years. Although teachers have been using systems thinking techniques in their classrooms and researchers have been testing the effect of systems thinking teaching on students' critical thinking and decision-making skills, there is still no clear definition of systems thinking or identification of the best method to test the effectiveness of systems thinking (ST) interventions. The lack of a clear definition and standard assessment measures is a problem because we are advocating the teaching of systems thinking in the classroom without any consensus on what we are teaching or how best to teach it. The goal of this paper is to answer the question: how do we assess the effectiveness of systems thinking interventions in education? In order to answer this question, I had to address the following 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?

Systems Thinking Interventions in the Classroom

The majority of information about systems thinking in literature comes from anecdotal observations by teachers in the classroom. Teachers and researchers advocate systems thinking interventions in the classroom because they believe that systems thinking characteristics are important for students to develop. Grant (1998) states that in environmental science education, problem solving and communication skills are difficult to teach. Traditional learning, with students lectured to by teachers, results in students passively receiving and memorizing large quantities of fragmented information. Conversely, Grant (1998) reports that with the systems approach learning is integrative and students are active learners. Students develop critical thinking and problem solving skills (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 in education has shown that active learning creates a longer lasting understanding of scientific concepts, skills, and the nature of science (Leonard, Speziale, and Penick, 2001).

Researchers argue that not only do students become active learners with systems techniques, but also the learning environment becomes more learner-centered. In these classrooms, teachers act as guides while the student directs their own learning (Lyneis and Fox-Melanson, 2001, Milrad, 2002). Lyneis, Stuntz, et al. (2002) report that students develop the skills and perspective in order to deal with the dynamic world outside of the classroom. Teachers and

researchers believe that with a systems perspective, students understand interdependencies, long and short-term decisions, and consequences of their own actions within a system (Lyneis, Stuntz, et al., 2002; 4).

Although the information from classroom observations and experience is important as a starting point in investigating the effect of systems thinking interventions in education, these reports (1) do not specify what they want to change, (2) do not give enough information on what they are doing, and (3) do not provide strong evidence to support their claims. Evidence from these reports is mostly anecdotal. Although researchers in the field of systems thinking have written about the need for more rigorous evidence about the effectiveness of systems thinking information, there is still little information about the topic (Costello, 2001, Hight, 1995, Maani and Maharaj, 2002, and Sweeney and Sterman, 2000).

Significance of the Study

This paper presents an initial definition of systems thinking, including a proposed framework for characterizing the attributes of a systems thinker, and an analysis of systems thinking interventions in the field of education. The audience for this paper is the community of researchers and teachers teaching systems thinking in the classroom. Although this research was motivated by discussions in the system dynamics community, the results are intended for the general audience of teachers and researcher that use systems thinking interventions in kindergarten through post-graduate classrooms. The aim of this paper is to

advance efforts to promote systems thinking by developing more concrete guidance for assessing systems thinking interventions.

CHAPTER 2

APPROACH

In order to answer the central question posed in this research, I first had to answer the sub questions. This research was divided into six parts:

- (1) Research of the general body of literature about systems thinking
- (2) Identification systems thinking definitions and essential characteristics of systems thinkers and examined Bloom's Taxonomy literature about assessment.
- (3) Development of a taxonomy of systems thinking characteristics, which is described in chapter 3.
- (4) The literature from the first step in this research was reviewed a second time to find the research on scientific studies about systems thinking interventions in education.
- (5) This literature was synthesized using a meta-synthesis structure (Creswell, 2002). The meta-synthesis allowed me to identify gaps in knowledge about systems thinking interventions.
- (6) Finally, I developed a preliminary set of best practices guidelines for systems thinking interventions that correspond with the application of Bloom's Taxonomy.

The purpose of these guidelines is to give teachers and researchers the ability to assess the effectiveness of systems thinking interventions.

Search Procedures

A comprehensive review of the literature was performed to identify studies about systems thinking in general, systems thinking definitions, and systems thinking interventions performed in kindergarten through post-graduate classrooms. This literature review was a comprehensive review of the systems literature and was used in all parts of this research. I reviewed this general pool of literature for each step to pull out the appropriate literature. Chapter three includes literature about systems thinking definitions and chapter four, five, and six include literature about systems thinking interventions in the classroom.

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. 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.

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. I 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 Listserv 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 one 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.

This paper is intended for the general systems thinking audience, not just the system dynamics community. Although I reviewed systems thinking literature from many different fields, the majority of the literature came from the field of system dynamics, as shown in Table 1.

Table 1: Systems Thinking Literature Identified per Field

Field	Number of articles, books, or other published reports
System Dynamics	70
Health	10
Education	5
Science	10
Business / Management	5

CHAPTER 3

DEVELOPMENT OF A SYSTEMS THINKING TAXONOMY

The following chapter was originally published in the proceedings of the 25th International Conference of the System Dynamics Society in Boston, Massachusetts (Stave and Hopper, 2007) and presented at the conference. This paper was specifically developed for the system dynamics community as an initial framework for measuring a person's systems thinking ability. My role was to investigate existing frameworks to measure systems thinking abilities. When I determined that there were no existing frameworks being used broadly, I research in the education literature for general thinking assessments. This research led me to the literature about Bloom's Taxonomy. With the literature about Bloom's Taxonomy, I mapped Bloom's Taxonomy onto the systems thinking characteristics. I also participated in the design and administration of a survey at the 2006 Systems Thinking and Dynamic Modeling for K-12 Conference, and assessment of the literature. Krystyna Stave and I co-authored the paper.

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: "A... 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

¹ Associate Professor and Graduate Student, respectively. Students Stephanie Fincher, Erin Jolley, Jeff Joyce, and Amy Miller participated in the design of the project, conducted the Phase 1 survey, and contributed to an early draft of this paper.

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 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 are 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 Sees things, not relationships Sees Cause-effect relations as one-way One cause/one effect External events cause system Reaction	a fully realized systems thinker Sees relationships rather than things Sees cause-effect relations as reciprocal Multiple causes/multiple effects 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 2 shows the responses from the six who did give full rankings.

Table 2. 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 3 because they did not specifically define systems thinking. For example, Daniel Kim has written many articles

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.

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.

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 3. Key Characteristics of Systems Thinking

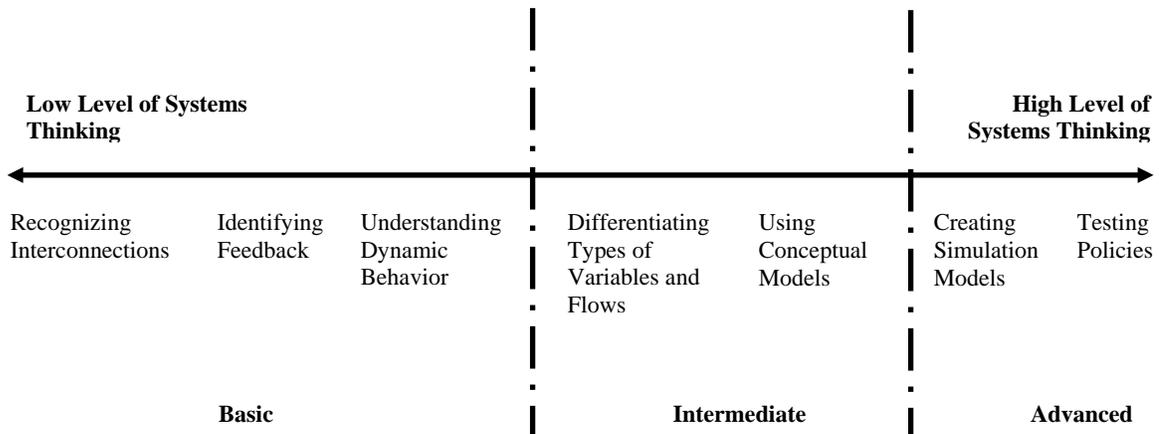
	Recognizing Interconnections	Identifying Feedback	Understanding Dynamic Behavior	Differentiating types of flows and variables	Using conceptual models	Creating simulation models	Testing policies
Citation	Seeing the whole system, understanding how parts relate to and make up wholes, recognizing emergent 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,			X	X		X	

Langerfelder, and Biber 2006							
Maani and Maharaj 2002	X	X	X			X	X
Maani and Maharaj 2004	X	X	X			X	X
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 3 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.

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.

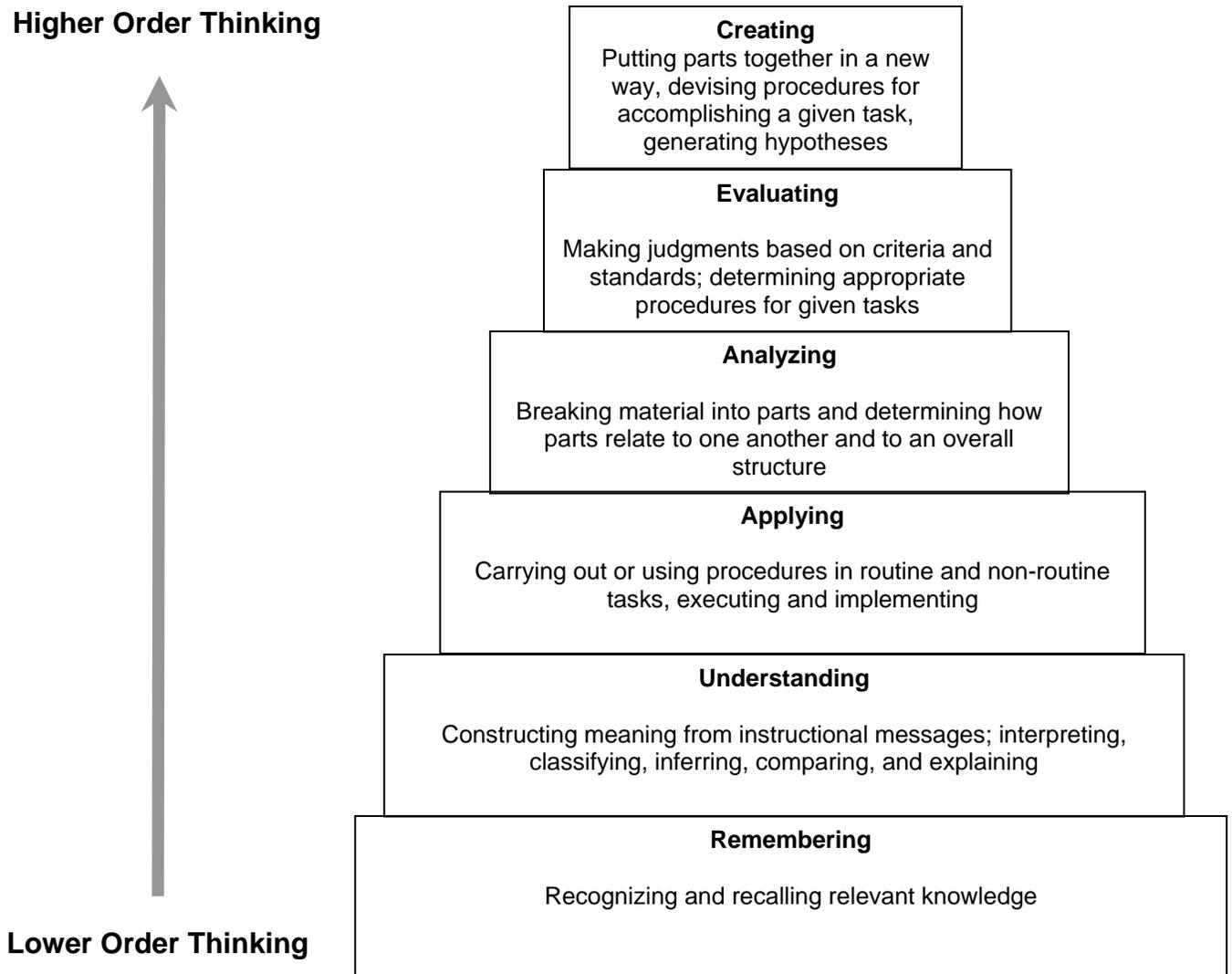
The second level of Bloom's revised taxonomy is **Understanding**, defined as being able to construct meaning from instruction. Objectives for learning at this level include the ability to interpret, exemplify, classify, summarize, infer, compare, and explain information. Interpreting is the process 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.

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



Mapping Bloom's Taxonomy onto Systems Thinking

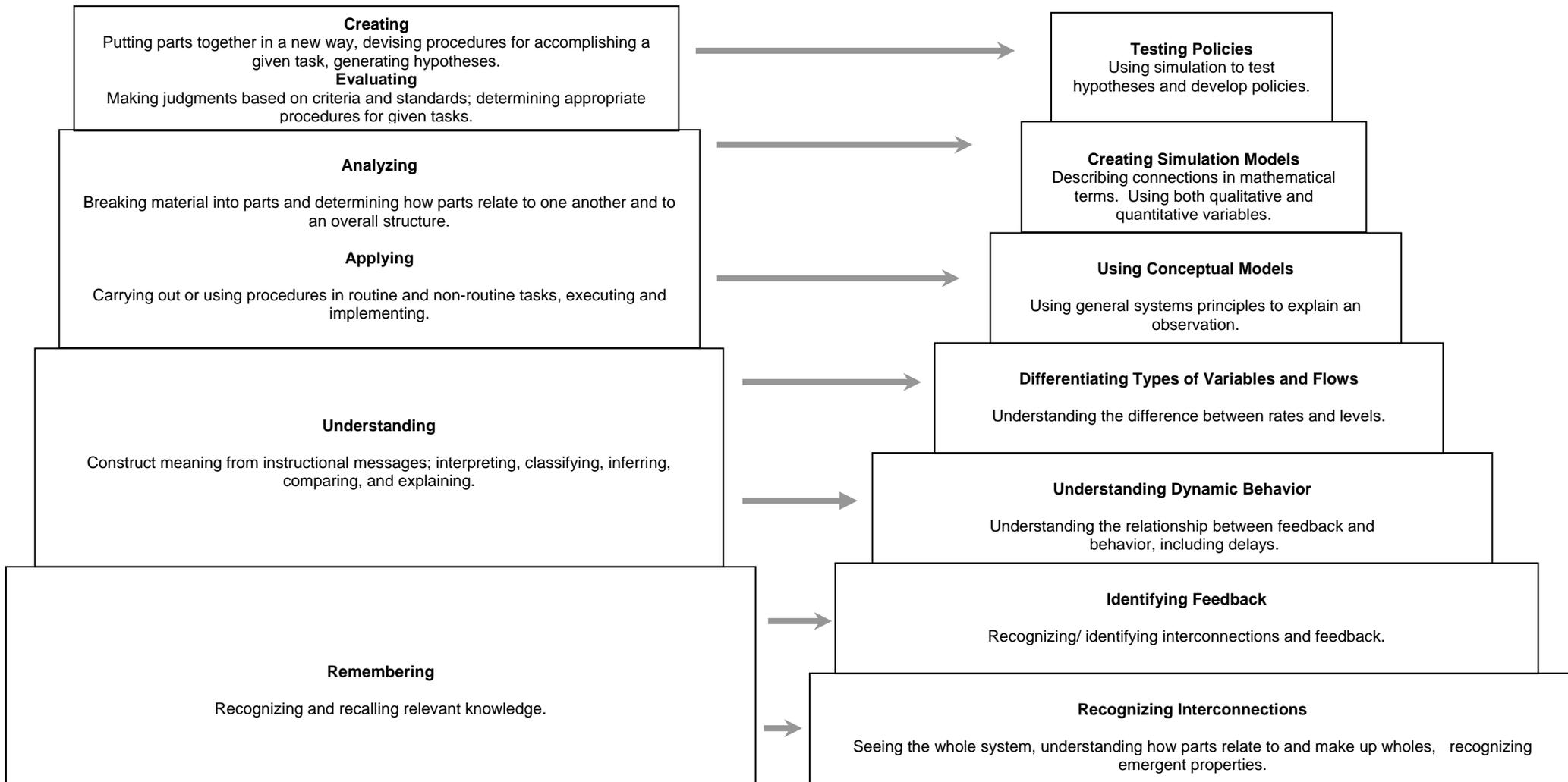
We compared the seven key components and the continuum derived from the literature to the levels of learning objectives in Bloom's taxonomy to create our proposed taxonomy of systems thinking characteristics. Figure 4 shows the relationship between the two sets of concepts. For the purposes of developing 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 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.

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



Based on the resulting Taxonomy of Systems Thinking Objectives, we developed an initial set of assessment measures, shown in Table 4. 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 4. 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	<ul style="list-style-type: none"> - 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 	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - Recognize chains of causal links - Identify closed loops - Describe polarity of a link - Determine the polarity of a loop 	<ul style="list-style-type: none"> - Representation of causality and loops in words or diagrams - Diagram indicating polarity
Understanding Dynamic Behavior	<ul style="list-style-type: none"> - 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 	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - 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 	<ul style="list-style-type: none"> - Table of system variables by type - Types of variables with units
Using conceptual models	<ul style="list-style-type: none"> - Use a conceptual model of system structure to suggest potential solutions to a problem 	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - Represent relationships between variables in mathematical terms - Build a functioning model - Operate the model - Validate the model 	<ul style="list-style-type: none"> - Model equations - Simulation model - Model run - Compare model output to observed behavior
Testing policies	<ul style="list-style-type: none"> - 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 	<ul style="list-style-type: none"> - 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 than 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.

CHAPTER 4

META-SYNTHESIS METHODS

The fourth step of this investigation was to survey the literature reporting on scientific studies on systems thinking interventions in kindergarten through post-graduate education. The goal of this literature review was to identify systems thinking assessment measures. The methods for the literature review for this chapter are described in Chapter 2. The literature identified through the methods previously described were reviewed a second time in order to identify interventions that used the scientific method. The final chapters of this paper describe the steps used to analyze this scientific research. These steps and consisted of (1) identifying papers describing scientific studies from the literature review, (2) evaluating the systems literature through a meta-synthesis in order to make conclusions about the effectiveness of systems thinking interventions, and (3) developing best practices guidelines for systems thinking interventions that correspond with the application of Bloom's Taxonomy.

Selection Criteria

A third review of the literature from Chapter 2 was performed to identify scientific studies about systems thinking interventions performed in kindergarten

to post-graduate classrooms. Studies that used an intervention within an educational setting in order to measure or raise a person's level of systems thinking were considered relevant for inclusion in this paper. Papers published on classroom lessons that did not describe a specific research protocol were not included. These papers are reported on in Chapter one of this paper, but were not included in this meta-synthesis because the purpose of these lessons was not to answer a specific research question.

Data Analysis

From the pool of 100 papers described in chapter 2, I re-reviewed the papers using the following criteria: the research (1) had a specific research question, (2) used the scientific method, (3) tested a systems thinking intervention in a kindergarten-post-graduate-level classroom, and (4) tested the effectiveness of the intervention in measuring or raising a person's level of systems thinking. Of the 100 papers and books researched, only fourteen papers met the criteria. I examined the fourteen papers using the following categories: background information, classroom characteristics, intervention characteristics, and assessment of impact of intervention were recorded. These categories are discussed in further detail below.

Background Information: Background information recorded about the studies included, author(s), title, source, and date of publication.

Classroom Characteristics: For classroom characteristics, I recorded the grade level of the students, number of students who completed the intervention, the subject taught (Biology, English), and whether the students had systems thinking or system dynamics experience in the class that the intervention took place in.

Interventions Characteristics: The following data was collected about the type of intervention performed in the classroom: type of intervention (computer, worksheets), research method (pre-test/post-test, post-test), description of intervention, and systems thinking skills tested using the taxonomy created by Stave and Hopper (2007).

Assessment of Impact of Intervention: All descriptions about the results of the studies were collected and listed by systems thinking skills tested.

All reports were read at least once before the information was coded into the above categories. During the initial reading, I took notes, wrote comments, and highlighted significant text. After the first reading, I began the process of coding to identify and code all important information within the studies. Coding decisions were revisited approximately four times for each study, in order to identify all important information. Some categories of information that appeared important during the first review of the literature were found to be less important in the literature and for the purposes of this paper. For example, the author's

definition of systems thinking seemed to be important before the analysis of interventions; however, only three authors gave a definition of systems thinking.

Meta-Synthesis

I performed a meta-synthesis of the fourteen studies selected. A research synthesis is an “attempt to integrate systematically a large body of related research literature” (Scruggs, Mastropieri, and McDuffie, 2007; 394). Sandelowski, Docherty, and Emden (1997; 365-366) define a meta-synthesis as “the theories, grand narratives, generalizations, or interpretive translations produced from the integration or comparison of findings from qualitative studies.” Scruggs, Mastropieri, and McDuffie (2007; 394) found that research on co-teaching consisted of individual studies that had not been summarized or synthesized. The literature on systems thinking is similarly unorganized. In order to understand systems thinking interventions, it is important to synthesize the relevant data. Sandelowski, Docherty, and Emden (1997; 365) state that in order for qualitative studies to be useful, they must be “situated in a larger interpretive context” and put in an “accessible and usable form.” The purpose of this synthesis is to organize the systems thinking research in order to assess what we know about systems thinking.

Steps in Qualitative Data Analysis

In order to conduct a qualitative data analysis and interpretation, Creswell (2002; 257) suggests the following steps:

1. Prepare and organize the data for analysis
2. Explore the data
3. Describe and develop themes from the data
4. Represent and report the findings
5. Interpret the findings
6. Validate the accuracy and credibility of the findings

The first step in a meta-synthesis is to *organize the data* from the research. The initial data organization for this thesis consisted of file folders and an Excel matrix, which contained the background information from all studies. After the data was organized, data analysis began. *Exploring the data* consists of reading over the information several times in order to get a preliminary understanding of all the information. Once I developed a preliminary understanding of the data, I began to *describe the information and develop themes*. Creswell (2002; 266) describes this process as identifying text segments and assigning a code or word that describes the meaning of the text. The large number of codes found in the research are aggregated together to form major themes from the information. The final two chapters in this thesis, results and discussion, will *describe and interpret the findings* (Creswell, 2002).

CHAPTER 5

META-SYNTHESIS RESULTS

Meta-Synthesis Results

Based on the literature review, I found fourteen systems thinking interventions within the education field that met all of the requirements for selecting cases that I created. Table 5 shows the information collected from these papers, which will be described in further detail below. The following is a summary of each category shown in Table 5.

ST or SD Experience: Students in six interventions had experience with either learning about systems thinking or practice with system dynamics modeling prior to the testing. This experience ranged from very little experience, playing the beer game or working with behavior over time graphs (BOTGs), to five years of instruction in modeling. Four studies used a pretest/posttest design, with three of the four lecturing about systems thinking prior to the posttest. The fourth study used an integration activity to help student's link concepts causally before the posttest.

Table 5: 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
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.	<p>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.</p>
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-	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)	Microworld	Testing Policies - Students made decisions about the business that they were running through the simulation.

				behavior assumptions, surfacing assumptions, and causal tracing.		and then asked to 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.

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
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.
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.

Description of the Study: 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. 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 in Chapter 3. Table 3 summarizes the results. 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 6 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 6: 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	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - Representation of causality and loops in words or diagrams - Diagram indicating polarity 	
Understanding Dynamic Behavior	<ul style="list-style-type: none"> - 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 	<ul style="list-style-type: none"> - Manufacturing Task (Asks students to determine a trend in the presence of a delay and negative feedback.

	behavior	
Differentiating types of variables and flows	<ul style="list-style-type: none"> - Table of system variables by type - Types of variables with units 	<ul style="list-style-type: none"> - Bathtub and Cash Flow Tasks (Ask students to determine how the quantity of a stock changes based on its flow.)
Using conceptual models	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - Model equations - Simulation model - Model run - Compare model output to observed behavior 	
Testing policies	<ul style="list-style-type: none"> - 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 7. 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.

Table 7: Systems Thinking Characteristics Tested by SystemsThinking 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			

One of the problems with these interventions is that the researchers do not specifically state what type of systems thinking skill they are testing. Using the descriptions of the interventions, I mapped which systems thinking characteristics the authors were testing onto Stave and Hopper's (2007) systems thinking taxonomy. Dhawan, O'Connor, and Borman (2006; 3) state that students were taught systems thinking and system dynamics modeling material that was drawn from standard systems thinking and system dynamics text. These lectures "covered the majority of the concepts of these two methods" (Dhawan, O'Connor, and Borman, 2006; 3). The authors of this study tested students' ability to understand dynamic behavior, differentiate between the types of variables and flows, and test policies.

Duangploy and Shelton (2000; 82) hypothesized that using the systems approach to learning business “will lead to a higher level of thinking skills (the ability to recognize similarities and differences between learned elimination entries and other elimination entries).” The authors do not specify what the systems approach is, so based on the description given by Duangploy and Shelton (2000; 83) that students must learn the “objective, then formulate the journal entries,...and observe the output.” I interpreted this information to mean that the researchers are testing the students’ understanding of dynamic behavior.

Table 8 shows the specific 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 measuring the same ability. Each of the tests shown in Table 9 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 4.

Assaraf and Orion (2005) utilized six types of assessments in order to test students’ ability to recognize interconnections, identify feedback, understand dynamic behavior, and use conceptual models. By using several different types of assessments, the researchers were able to assess the students’ ability to recognize interconnections, identify feedback, understand dynamic behavior, and

use conceptual models. These types of assessments are useful because students can show their ability at different levels in several different ways. One study does not give a picture of whether these assessment measures are effective at testing students' systems thinking ability, however. These measures need to be further analyzed.

Table 8: 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
Questionnaire	Questionnaire	Repertory Grid	Calculation of Variables	Drawing Analysis	Development of Model	Microworld (Simulation Testing)
Drawing Analysis	Drawing Analysis	Questionnaire		Concept Maps		Questionnaire
Word Association	Concept Maps	Problem Sets				
Concept Maps						
Interviews						
Repertory Grid						
Integration Activity						

Only one intervention tested students' ability to create simulation models. Students were asked to model a situation, analyze the outputs, and perform sensitivity analysis (Dhawan, O'Connor, and Borman, 2006). Although there is only one type of assessment in this category, the assessment is appropriate for the level. Both Dhawan, O'Connor, and Borman (2006) and Cavaleri, Raphael, and Filletti (2002) assessed students' ability to test policies. Cavaleri, Raphael, and Filletti (2002) allowed students to use a microworld to make decisions about a business. This top category needs to be better developed in order to

determine if students are testing realistic policies rather than simply playing with a simulation model. Students need to show that they can understand policy levers and the behavior that changing these levers results in; otherwise they are not showing an understanding in this top category.

Results: This section presents the results of the fourteen studies. Assaraf and Orion (2005) used seven types of measures to assess students' level of systems thinking after a unit on the hydrologic cycle. The authors found that although students started at a lower level of systems thinking, by the end of the unit they had increased their systems thinking ability. Assaraf and Orion (2005) state that the highest level of systems thinking for the hydrologic cycle unit was thinking temporally, which a third of the students reached.

Based on their research, Cavaleri, Raphael, and Filletti (2002) found that students needed a lot of practice using systems tools before they show an increase in their level of systems thinking. Ginsberg and Morecroft (1995) found causal loop diagrams useful in provoking dialogue between students. Some of the students in their class found the maps to be difficult to understand, however. The researchers suggested that the students needed an introduction to systems thinking concepts before starting the unit. Based on exam scores, Duangploy and Shelton (2000) found that students who were given a lecture on the systems approach had a better understanding of business combinations than a group that did not learn the systems approach. Kali, Orion, and Eylon (2003; 560) found that after a knowledge integration activity, students became more aware of the

“dynamic and cyclic nature” of the rock cycle. The authors suggest that systems-based curriculum should include (1) a stage of knowledge building in which each of the system’s components are studied and integrated into a whole, and (2) a “differentiation and reintegration concluding stage” (Kali, Orion, and Eylon, 2003; 563). Each of these researchers found that students need practice and time to develop their systems thinking abilities.

Students who participated in the Dhawan, O’Connor, and Borman (2006) intervention were given a case study and took a pretest and posttest, testing their understanding of dynamic behavior, differentiating types of variables and flows, creating simulation models, and testing policies. These students improved on their ability to identify and recognize key relationships, identify feedback and differentiate between stocks and flows after a short course on systems thinking. These conclusions were based on the fact that study participants could model the scenario appropriately and perform sensitivity analysis, and the authors found that the students performed better statistically from the pretest to the posttest. The authors stated that the students needed to create the simulation models and test policies in order to understand very complex problems (Dhawan, O’Connor, and Borman, 2006).

The eight researchers that utilized Sweeney and Sterman’s (2000) systems thinking inventory tasks had very mixed results. High school students in upper level math classes in Fisher’s (2003) study performed well on the bathtub task, based on results from the assessment. According to Fisher (2003), analyzing stocks and flows is a part of the curriculum in the calculus classes,

while the advanced algebra students study the relationship between distance and velocity. Both of these groups had difficulty on the cash flow task. The researcher attributed the calculus students' poor performance to lack of attention to detail and the algebra students' poor performance to lack of experience with this more difficult problem (Fischer, 2003).

The social science students in Heinbokel and Potash's (2003) study did not perform well on the bathtub task with the majority of students not answering the questions correctly. The researchers attributed this to the students' lack of knowledge about systemic behavior, who only had practice using behavior over time graphs. The researchers believe the performance was due to the lack of foundation more than their systems thinking abilities (Heinbokel and Potash, 2003).

Zaraza (2003) found that high school students with more than a year of systems thinking experience performed well on all of the tests. The researcher suggests that these results show that these students understand the ideas of stocks and flows. Although the manufacturing task uses business concepts, which high school students do not study, these students were able to translate their knowledge of stocks and flows to solve these problems (Zaraza, 2003).

Kainz and Ossimitz (2002), Kasperidus, Langfelder, and Biber (2006), Ossimitz (2002), Pala and Vennix (2005), and Sweeney and Sterman (2000) all tested college level students based on the tasks developed by Sweeney and Sterman (2000). Kainz and Ossimitz (2002) found that students who were given a 90 minute lecture on the basics of stocks and flows between a pretest and

posttest significantly improved their performance on the questions about stocks and flows. Similarly, the students in Pala and Vennix's (2005) study improved from the pretest to the posttest after a class on system dynamics in between the tests. The authors suggest that the improvement from the pretest to the posttest could be attributed to the system dynamics class.

Kasperidus, Langfelder, and Biber (2006) claim that the students in their study had a poor understanding of systems principles, which included students that had a lecture on systems thinking prior to the intervention. The students from Massachusetts Institute of Technology (MIT) (Sweeney and Sterman, 2000) and students from Viennese Universities (Ossimitz, 2002) performed similarly. Both groups showed a poor understanding of the concepts of stocks and flows, again with the majority of students answering the questions incorrectly. Although the students in the system dynamics class at MIT performed better than the students in the microeconomics class at WPI, the groups still did not perform well.

CHAPTER 6

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 8 showed, 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.

Best Practices Guidelines for Systems Thinking Interventions

After analyzing systems thinking interventions in the classroom, I revised Table 3, as shown 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 should be able to:	Products, Assessment Tests
Recognizing Interconnections	<ul style="list-style-type: none"> - 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 	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - Recognize chains of causal 	<ul style="list-style-type: none"> - Representation of causality

Feedback	links - Identify closed loops - Describe polarity of a link - Determine the polarity of a loop	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 - Identify units of measure for variables and flows	- Ability to move from a causal diagram to one that differentiates between the different types of variables - Table of system variables by type - 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	<ul style="list-style-type: none"> - Use a conceptual model of system structure to suggest potential solutions to a problem 	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - Represent relationships between variables in mathematical terms - Build a functioning model - Operate the model - Validate the model 	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - 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 	<ul style="list-style-type: none"> - 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.

Teachers and researchers can use the assessment measures in Table 9 to clarify the objectives of lesson plans and interventions to assess a student's systems thinking ability.

Insights

The purpose of this work was to answer the question of how to assess the effectiveness of systems thinking interventions in education. Chapter 3 presents an initial systems thinking taxonomy that was developed specifically for the system dynamics community. The system dynamics community believes that creating simulation models is at the top of the abilities for systems thinkers; however, this may not be 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.

Individuals within the systems dynamics community at the 25th International Conference of the System Dynamics Community suggested that the systems thinking continuum, see Figure 2, might be too linear. These people suggested that the continuum could be two dimensional. Figure 5 shows one potential two dimensional version of the systems thinking continuum. The systems thinking skills on the y-axis are the same as from the continuum and are arranged from lower order to higher order. The x-axis represents the degree of

development, which is also on a scale from low to high. The degree of development is a measure of how developed someone's skill are at a particular systems thinking level. A person could be low on the continuum of systems thinking skills, but be 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.

Figure 5: Two Dimensional Systems Thinking Continuum



The purpose of this paper was to identify ways to measure a person's level of systems thinking and ways to raise a person's level of systems thinking based on the research that has been performed. The conclusions drawn from

the research suggests that in order to raise a person's level of systems thinking, instructors need to follow the steps in the systems thinking taxonomy shown in Table 2. In order to assess a person's level of systems thinking, students need to demonstrate the products suggested for each level of the systems thinking taxonomy demonstrated in Table 9.

Since there were no set definitions of systems thinking characteristics or ways to test systems thinking, this paper took a step back from the process of running an intervention. This paper stops at the point of creating a taxonomy of systems thinking and suggesting ways to test and raise a person's level of systems thinking. Future work based on this work should test the taxonomy in order to further refine the definition and types of interventions.

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