Systems Thinking, Pattern Thinking, and Abductive Thinking as the Key Elements of Complex Learning

Jeffrey W. Bloom
College of Education
Northern Arizona University
Flagstaff, AZ 86011
jeff.bloom@nau.edu

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The present paper describes a novel model of teaching for complex learning that will also increase students' abilities to transfer their knowledge across subject matter domains. This paper focuses on how the model affects student learning and transfer. In general, this theoretical model suggests that the implementation of such an approach will:

1. Increase children's complex learning, which includes in-depth conceptual understandings, abstract explanatory models and principles, and connections across subject matter areas.
2. Increase children's ability to transfer knowledge across subject matter areas and other experiential contexts, including language and culture.
3. Increase children's achievement levels without teaching directly to the test.
4. Increase our understandings of how children develop complex understandings that can be transferred across subject matter domains and other contexts.
5. Increase our understanding of the effectiveness of different teaching styles and approaches in implementing a model of teaching for complex and transferable understandings.

Context

Although student achievement in reading, writing, mathematics, science, and other subject matter areas has been increasing, the United States still lags behind other countries (Gonzales, et al., 2009). Such mediocre indicators of achievement across the United States are of increasing concern as we enter a period of time when we will need to draw on our youth as they enter adulthood to solve the numerous and complex problems that face our society. While we have extensive data on achievement, we do not necessarily know how this data is correlated with student learning and understanding. Reasons for low achievement scores vary. However, such low scores may suggest (a) that students are not learning to a satisfactory degree or (b) that they lack the ability to transfer what has been learned to assessment tasks. As a result of such low levels of achievement many schools have resorted to requiring teachers to teach-to-the-test. In the short term, such efforts raise test scores, but do little to affect students' in-depth understandings and have resulted in student learning that is disconnected, fragmented, and trivialized (Oliver & Gershman, 1989). In addition, such direct approaches to instruction tend to limit the relevance, meaning, and applicability of the subject matter material. For students, such teaching strategies negatively affect motivation, engagement, and interest in learning. For teachers, these approaches to teaching undermine their professionalism and may contribute to decreases in job satisfaction and retention.

While the National Science Education Standards (NRC, 1996) call for teachers to utilize strategies that include student-directed inquiry, student model and explanation building, and other rigorous approaches to developing in-depth understandings, very few teachers use these strategies (Roth, et al., 2006), not to mention other strategies that could lead to dramatic increases in learning and transfer. It is important to note that the teaching and learning approaches suggested by the science education community also are appropriate to other subject matter areas. For instance, explanation building, modeling, inquiry, and other approaches, such as problem solving and project-based approaches, are essential to learning in mathematics, reading, writing, social studies, and the arts. At the same time, many of the fundamental concepts in these subject matter areas are shared. For instance, cycles are important throughout the science disciplines (e.g., carbon cycle, Kreb's citric acid cycle, water cycle, sound waves, electromagnetic waves), in mathematics (e.g., algorithms and patterns), in the arts (from processes to subject matter, in dance and music patterns), in literature (as plot and character development), and social studies (e.g., economic and political cycles, social interactions). In addition, cycles also appear throughout the everyday lives of children (e.g., daily patterns, their play, games) and in their social and cultural contexts (e.g., belief systems, rituals). Although the specific details of understanding cycles in each subject matter areas and contexts vary, the basic concept that "cycles maintain some system or process" is shared across all subject matter areas and contexts. While many of these concepts and patterns are ubiquitous, curriculum and teachers do little to help students make these connections. Even within subject matter areas, very few teachers emphasize making conceptual connections (Roth, et al., 2006).

In addition, many teachers are receiving mixed messages from administrators. On the one hand, they are told to engage children in active learning including inquiry and other hands-on/minds-on approaches. On the other hand, they are told to raise test scores by using direct instruction or by teaching-to-the-test (Bloom, 2002). These mixed messages leave teachers in a bind that is not easy to rectify. Only a very few teachers are willing to take the risk to use instructional approaches that result in deeper learning. However, even with the best of intentions, many teachers lack the content knowledge, pedagogical content knowledge, pedagogical knowledge, and support to teach in ways that use inquiry, problem solving, explanation building, and other authentic knowledge building approaches to probe the depth of subject matter areas and to make connections across subject matter areas. From the TIMMS study in 1999, grade-8 science lessons in the United States were taught in ways that only 30% of these lessons made strong conceptual links to the subject matter, while 44% made weak or no conceptual links, and the remaining 27% had students do activities that made no conceptual links. In Australia, 58% of the comparable science lessons made strong conceptual links. In Japan, 70% of these lessons made strong conceptual links (AERA, 2007). There are no data on the conceptual links *across* subject matter areas. If we want students to be able to transfer their learning to new situations, we need to begin by making conceptual links both within and *across* subject matter disciplines. Up to this point in time there is little, if any, evidence that transfer of knowledge occurs to any significant degree among students at any level of schooling (Haskell, 2001).

Bransford, Brown, and Cocking (2000) and the National Science Education Standards (NRC, 1996) state that we should be teaching in ways that produce deeply complex, integrated, and long-term learning. However, very little research has been conducted that sheds light on the nature, extent, and teaching of complex, integrated concepts at any age level. Only one research project has addressed complex thinking, but not complex conceptual learning (see the "Five Standards for Effective Pedagogy" [CREDE, 2003a, 2003b, 2003c]). Other research that emphasizes the learning of "Big Ideas" involves learning in a school community addressed in a book by Rogoff, Turkanis, and Bartlett (2001), but this work does not include any research on the learning outcomes of students.

Theoretical Model

This paper proposes a model of learning that is based on (a) ***systems thinking*** *(Bateson, 1979/2002; Checkland, 1985; Paucar-Caceres & Pagano, 2009; Roberts, 1978; Weinberg, 1975/2001),* (b) ***pattern thinking*** (Bateson, 1979/2002; Bloom, 2006a; Bloom & Volk, 2007; Coward, 1990; Thomas, 1987), (c) ***abductive thinking*** (Aliseda, 2003; Bateson, 1979/2002;

Kapitan, 1992; Niiniluoto, 1999; Thagard & Shelley, 1997), and (d) other ***social constructivist approaches to learning and inquiry*** (Bloom, 2006a; various authors in Steffe & Gale, 1995). Such a model may increase (a) the *complexity of students' conceptual understandings* and (b) students' abilities to *transfer knowledge*. In addition to these cognitive gains, it is likely that student engagement and motivation also will increase.

This model of teaching for complex, transferable learning (see Figure 1) represents a recursive approach to inquiring into increasingly specific questions about phenomena, while recursively applying the results of such inquiries (knowledge claims) to other contexts from those closely associated to the particular topic of inquiry to those of high levels of dissimilarity. For example, students can move their inquiries from earthworm cycles of movement to other animal and human movement cycles, then to mechanical movement cycles, ecological cycles, astronomical cycles, to other types of cycles in everyday life, social studies, arts, mathematics, etc.). As students develop greater depths of understanding and compare and contrast their knowledge claims across contexts, they are involved in a recursive process of developing abstractions, which are simplified explanatory principles and models that focus on those that explain, for example, the fundamental function of all cycles (i.e., to provide for the maintenance and continuity of a particular system), as well as the functions of context-specific cycles (e.g., coordinated control of cycles of muscle contractions for locomotion). Such an approach is consistent with authentic inquiry as an approach to probing into the functions, interactions, and relationships within specific phenomena. Applying the knowledge claim results from such inquiries across contexts not only models knowledge transfer, but also provides for the development of thinking skills that discriminate functional concepts and variations in meanings across contexts. The abstraction component directly addresses the emphasis on the development of models and other explanatory principles. The theoretical components of this model will now be discussed in more detail.

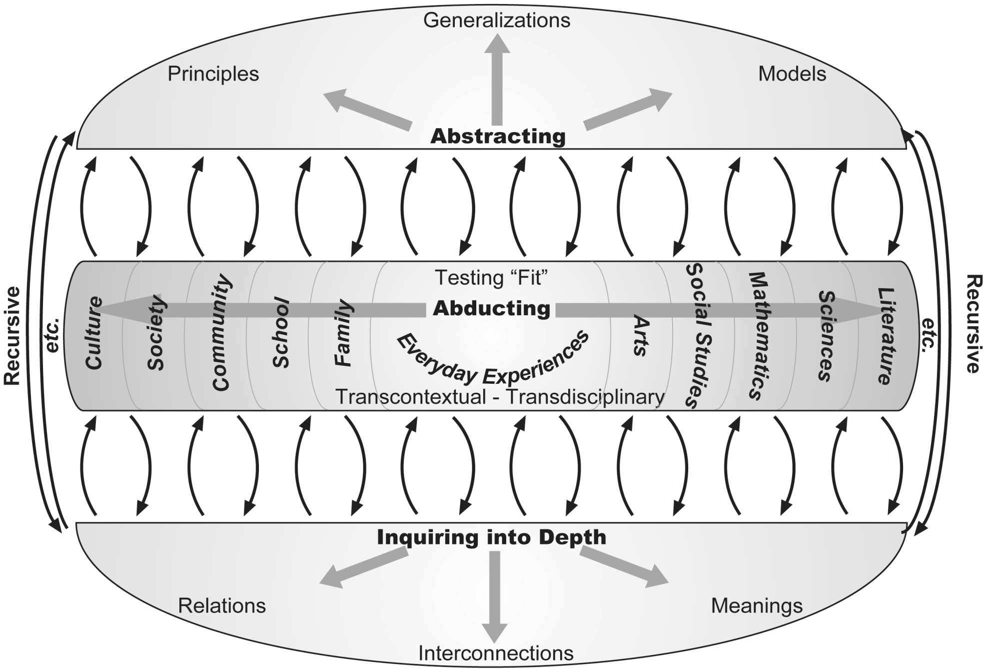


Figure 1. Recursive, triadic model of learning for complex understandings and transfer: Three dimensions of depth, abstraction, and abduction.

Systems Thinking. Systems thinking as a conceptual focus arose from cybernetics and its ensuing elaboration in systems theories. The basic idea of systems thinking involves moving away from a reductionist approach to learning and thinking to an approach that constantly refers to the "whole" system as the fundamental point of reference. Table 1 lists the overall characteristics, foci, thinking process, and concerns involved in systems thinking. However, the major intent of such an approach to thinking focuses on trying to develop understandings of whole systems that account for the functioning of all parts, their interrelationships, and the contexts in which the systems occur. In the sciences, all of the conceptual content is contained within one or more systems, whether these are mechanical, biological, geological, chemical, ecological, or mathematical systems. In the social sciences, we can look at psychological, social, cultural, economic, and political systems. The arts are embedded in various systems that range from perceptual to expressive systems and that share understandings of systems with the social and natural sciences. Languages and their written forms are systems in themselves. While languages are comprised of parts that contribute to greater cultural wholes, they also manifest as systems of communication and expression. Thinking and in-depth learning, which are heavily situated in language, are cognitive systems that left to their own focus on wholes, interrelationships, and complex connections. Young children's thinking is characterized by the foci and processes of systems (Bloom, 1990, 1992), but the longer they stay in school, the less they continue to think in this way as the emphases change to linear approaches to remembering fragmented and disconnected content (Waldron, P. W., Collie, T. R., & Davies, C. M. W., 1999). However, previous attempts at teaching systems thinking to upper elementary school children has been shown to be effective in children's learning about social problems (Roberts, 1978), but such an approach to thinking has never been adopted in schools and has received very little attention as the subject of educational research since that time.

The dimensions of systems thinking occur along three intersecting continuums that result in a kind of systems thinking space (see Figure 2). Such thinking can focus on inquiring into and understanding a variety of systems that are situated somewhere within the systems space delineated by the continuums (a) of simple to complex, (b) from single system to multiple, interacting systems, and (c) from contextually bounded to applied across contexts. For example, a bicycle is a simple, but multiple, interacting mechanical system. Typically, this is the extent of the study of such a system. However, a bicycle is nothing without a rider. So, now we add the biological and cognitive systems, including emotions, of the rider. This addition of the rider begins to move the object of study towards the "complex" end of the continuum and further towards the "multiple, interacting systems" end, as well. In addition, the rider suggests a context of human use. However, depending upon how far we want to go with this, the contextual continuum can be expanded to examining how bicycles are used in various situations, such as those involved in recreation, competition, and transportation. These situational contexts can vary further in specific cultural contexts such as bicycle use in the United States, China, India, Kenya, and the United Kingdom. In each of these cultural contexts, the meaning and function of bicycles vary.

Table 1. Summary of systems thinking.

OVERALL CHARACTERISTICS	
◆ Systems thinkers are Generalists	
◆ Systems thinking has a distinctive Worldview & Paradigm	
FOCI	**THINKING PROCESSES**
◆ ***Whole Systems***	◆ ***Non-Linear Thinking*** → looping, divergent, & convergent
◆ ***Relationships*** → relationships between parts & processes	◆ ***Questioning*** → posing penetrating & discriminating questions
◆ ***Feedback Loops & Other Non-Linear Processes*** of information flow involved in regulation & adaptation	◆ ***Polarizing*** → examining tensions, dilemmas, conflicting view and variables, & other oppositional binaries
◆ ***Transformation*** → change & transformational processes	◆ ***Modeling*** → developing & refining explanatory models, principles, laws, etc.
◆ ***Parts*** → all parts are important, but the sum of them is less than the whole	◆ ***Evaluating*** → critical examination of assumptions, variables, qualities, states, etc.
◆ ***Relevance & Usefulness*** → outcomes and results are not as important as relevance or usefulness	◆ ***Stochastic*** → random variation & processes are critical to systems thinking
CONCERNS	
◆ ***"Difference"*** is critical to understanding	◆ ***Identity*** of systems is based on difference
◆ ***System Survival*** is a ***Selection Process***	◆ ***Uncertainty*** is part of the nature of systems
◆ ***Multiple Perspectives*** → for understanding	◆ ***Complexity*** of variables and processes
◆ ***Boundary Problems*** → artificially creating reductionist separations	◆ ***Stability*** → based on relationships, not on goals or end-products; it is not linear

NOTE: This table is compiled from the works of Bateson (1979/2002); Checkland (1985); Daellenbachand & Petty (2000); Paucar & Pagano (2009); Roberts (1978); Ulrich (2003); Weinberg (1975/2001); and Werhane (2002)

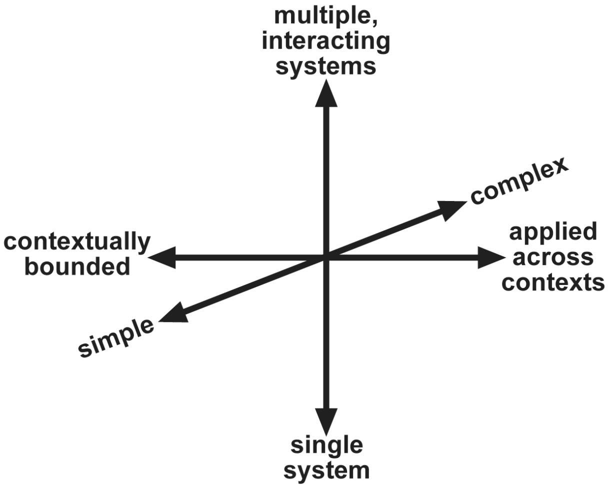


Figure 2. Intersecting dimensional continua of systems thinking.

Pattern Thinking. Pattern thinking is fundamentally at the core of all human thinking, in which the brain functions as a pattern recognizer (Anderson, J. R., Bothell, D., Byrne, M., Douglass, S., Lebiere, C., & Qin, Y., 2004; Weinberg, 1975/2001). However, even with this basic functionality, much of the way we approach thinking and learning does not take full advantage of our capabilities as pattern thinkers. Table 2 summarizes the overall characteristics, foci, thinking processes, and concerns involved in a more fully developed sense of pattern thinking. A fundamental operational view of pattern thinking involves a recursive approach to a loosely organized sequence of (a) recognizing patterns, (b) analyzing the functions and/or meanings of these patterns, (c) analyzing how these patterns are situated within one or more contexts, (d) finding these patterns in other contexts, and (e) using (applying, testing, analyzing, etc.) these patterns from one context in other contexts.

Although we have known that the brain functions as a pattern processor for some time, very little work has been done to develop this area in terms of learning. Beyond the early classic works of Weinberg (1975/2001) and Bateson (1979/2002), the only emphasis in this area has been in research on categorization (Varela, Thompson, & Rosch, 1991) and more recent work in a revision of schema theory (McVee, Dunsmore, & Gavelek, 2005). However, these research areas have not developed the idea of pattern thinking as an approach to learning. The only application of pattern thinking arose in semiotics over two decades ago. In this application, Thomas (1987) describes a four-step pattern thinking approach:

1. ***Replication*** – Aligning with subject matter disciplines [***in this paper's model***: analyzing functions, meanings, and situated-ness within context]
2. ***Historical Association*** – Organizing historically (over time) [***in this paper's model***: analyzing situated-ness within one or more contexts]
3. ***Correlation*** – Correlating knowledge claims across disciplines and contexts (epistemological) [***in this paper's model***: using or testing patterns across contexts]
4. ***Coalescence*** – Attempting to unify knowledge from across disciplines by focusing on relationships and meta-relationships [***in this paper's model of complex learning***: recursive approach to abstraction and extent or abduction across contexts]

The basic functional or operational characteristics of this approach involve (a) making connections (or emphasizing relationships), (b) expanding connection-making across contexts (i.e., extent or abduction in this paper's model), (c) developing broad explanatory principles (i.e., abstraction in this paper's model). Although relationships and principle development have been a concern of educators (Bransford, Brown, & Cocking, 2000; National Research Council, 1996) for some time, we have not been very successful at implementing these emphases.

Table 2. Summary of pattern thinking.

OVERALL CHARACTERISTICS	
◆ Pattern thinkers are ***Generalists***	
◆ Pattern thinking contributes to a distinctive ***Worldview*** & ***Paradigm***	
◆ Pattern thinking is ***Analytical & Aesthetic***	
◆ Pattern thinking is ***Transcontextual & Transdisciplinary***	
◆ Patterns are the material of ***Neuronal Function***	
FOCI	**THINKING PROCESSES**
◆ ***Patterns*** – repetitions in space, time, & mind	◆ ***Recognizing*** patterns (cascading pattern extraction)
◆ ***Relationships***	◆ ***Analyzing Functions & Meanings***
◆ ***Connections***	◆ ***Analyzing*** from ***Multiple Perspectives***
◆ ***Functions***	◆ ***Situating*** patterns ***in Context***
◆ ***Meanings***	◆ ***Locating*** patterns ***in Different Contexts***
◆ ***Adaptation***	◆ ***Evaluating & Testing***
◆ ***Complexity***	◆ ***Modeling***
◆ ***Recursiveness***	◆ ***Organizing***
◆ ***Models***	◆ ***Categorizing***
◆ ***Understandings***	◆ ***Associating*** – analogs, metaphors, etc.
◆ ***Similarities & Differences***	◆ ***Thinking Abductively***
CONCERNS	
◆ ***"Difference"*** is critical to ***Pattern Recognition*** & ***Understanding***	
◆ ***Assumptions***	◆ ***Systems***
◆ ***Transformative Learning***	◆ ***Complexity***
◆ ***Context***	◆ ***Connects & Disconnects***
NOTE: This table is compiled from the work of Bateson (1979/2002); Bloom (2004, 2006b); Bloom & Volk (2007); Coward (1990); Hofstadter (1979); Lakoff & Johnson (1980); Thomas (1987); Volk & Bloom (2007); and Volk, Bloom, & Richards (2007).	

From the perspective of learning that focuses on patterns, we need to consider Gee's (1997) assertion that,

> Because the world is infinitely full of potentially meaningful patterns and sub-patterns in any domain, something must guide the learner in selecting patterns and sub-patterns to focus on. This something resides in the cultural models of the learner's sociocultural groups and the practices and settings in which they are rooted. Because the mind is a pattern recognizer and there are infinite ways to pattern features of the world… the mind is social (really, cultural) in the sense that sociocultural practices and settings guide the patterns in terms of which the learner thinks, acts, talks, values, and interacts. (p. 240)

From this perspective, Gee is pointing to the notion of transdisciplinary, meaningful patterns and to the mind as a pattern recognizer. Certainly, the embodied nature of patterns in our biological and cultural minds lends itself to pattern recognition as a basic function of the mind.

Abductive Thinking. Abduction occurs all of the time, but is not addressed in most of the transfer literature, which will be discussed shortly. Although abductive reasoning has been utilized in anthropology and served as a major mode of thinking for Gregory Bateson (1979/2002; 1991), it has not been addressed to any significant degree in the psychological literature, with the exception of semiotics as introduced by Peirce (Stanford Encyclopedia of Philosophy, 2001/2006). Abduction is a reasoning process that examines how certain ideas "fit" across contexts. In considering that abduction needs to be taken into account, Thagard and Shelley (1997) have described a number of characteristics and results of abductive thinking that have a direct bearing on any discussion of transfer. When considering the construction of explanations as a major, recent emphasis in education (NRC, 1996), explanation may involve deduction and induction at some point in the process, but from Thagard and Shelley's perspective explanation itself is not deduction, but primarily an abductive process. At the same time, hypotheses and explanations are layered (either hierarchically or holarchically). In order to reason about hypotheses as layered ideas, abductive reasoning is required. Abduction is the process of thinking across hierarchic or holarchic layers. In addition, the abductive process can lead to creativity and the development of revolutionary hypotheses, which are not possible through merely deductive or inductive reasoning. Another characteristic of abduction, according to Thagard and Shelley, is that completeness is illusive. Further potentialities for developing relationships across contexts are always present. Another aspect of abduction involves the notion of simplification in that as ideas are addressed across contexts there is a process of simplification. However, Thagard and Shelley maintain that such simplification is a complex process. Their final characteristic of abduction is that the process may be visual and non-sentential or verbal in nature.

Bateson (1979/2002) considered abduction as a process of double or multiple description through the "lateral extension of abstract components of description" (pp. 157—158) as long as the same rules apply in both (or multiple) situations. From his perspective, the process of double description focused upon looking at the resemblances among differences, which, in his recursive vision, extended to seeing the resemblances of differences of resemblances of differences, and so on (Harries-Jones, 1995/2002). The notion of resemblances is fundamental to the Peircean semiotics inferential process. Shank and Cunningham (1996) have described six basic types of abductive inferences, which are, (a) ***omen/hunch***, which looks for possible resemblances from an initial observation; (b) ***symptom***, which looks at whether an initial observation has properties of a case or larger phenomenon; (c) ***metaphor/analogy***, which creates or discovers a rule from an initial resemblance; (d) ***clue***, takes an initial observation as a clue to a more general phenomenon; (e) ***diagnosis/scenario***, which creates a plausible scenario from a body of clues; and (f) ***explanation***, which develops a plausible explanation or formal rule from a set of observations, clues, or resemblances. Essentially, this more detailed description of abductive reasoning focuses on developing some form of explanation from one or more specific observations of similarity to multiple instances either within or across contexts. Such abductive thinking across contexts has been developed within systems thinking approaches, as well (Ulrich, 2003).

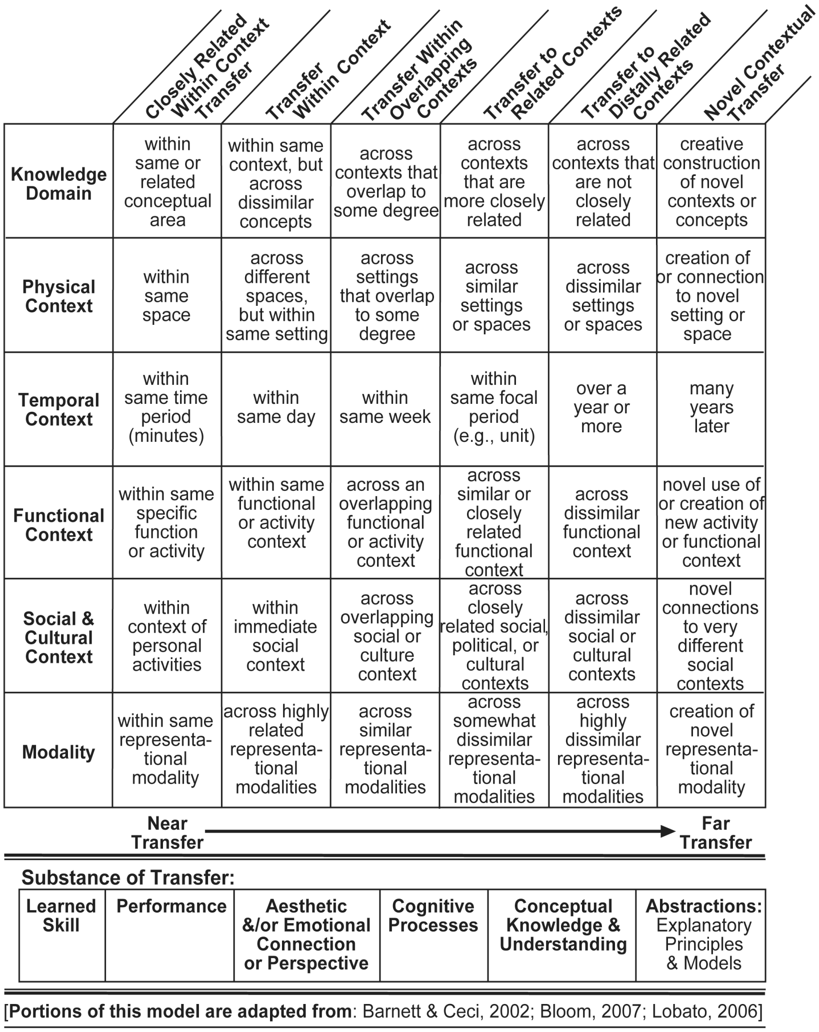
Learning and Transfer. Essentially, learning for transfer of knowledge involves abductive thinking and an extended sense of systems thinking. We commonly regard the thinking that is involved in such systems as ecosystems or transportation systems as systems thinking. However, this kind of systems thinking is very basic and limited in terms of its being limited to one particular system. At a more complex level, systems thinking extends beyond this limited view to the examination of multiple, interacting systems. Fundamentally, "systems thinking" examines the whole of complex, interacting, loops of contextually applied processes and the associated components and influencing factors involved in one system or in multiple interacting systems (Checkland, 1985; Goldstone & Wilensky, 2008; Werhane, P. H., 2002). Arising from this definition, we can delineate three dimensions of systems thinking that occur as continuums (see Figure 2). Along the first dimension, one examines simple to complex systems, such as from a simple mechanical system as with a bicycle to the complex system of an ecosystem. The second dimension spans from examining a single system, such as circulatory system, to examining multiple, interacting systems, such as all of the systems involved in a single organisms (i.e., circulatory system, nervous system, endocrine system, and so forth), which provide an understanding of how the whole is greater than the sum of its parts. The third dimension examines how patterns involved in one or more interacting systems can be applied to understanding one or more systems in different contexts. Some examples include how scholars have taken concepts (a) from ecology in the biological world and applied them to "cognitive ecology," (b) from biological evolution and applied them to "cultural evolution," and (c) from chaos and complexity theories in the natural sciences and applied them to chaos and complexity theories in the social sciences.

Both schema theory and theories of knowledge transfer have undergone revisions that now include the theoretical perspective of situated cognition, which has resulted in a view of learning where context is seen as the situated-ness of social practices. Although this move has had a remarkable and powerful effect on how we view learning and transfer, it still results in a limited view of context and what it may mean to transfer knowledge. Certainly, we are social beings and a vast majority, if not all, of what we learn is situated in our social contexts. However, we also spend considerable time putting personalized "spins" on and connections between the concepts and ideas we learn from a variety of social interactions. Such spins and connections can involve personal (and social) contexts of meaning (Bloom, 1990, 1992), subject matter domains as contexts, cultural and ethnic contexts, political contexts, physical and environmental contexts, and contexts of the imagination. In terms of transfer, these contexts can serve as the sources and targets of transfer.

According to Lobato (2006), current work in transfer defines three mechanisms: (a) Maxwell's (2004) ***process causality***, which addresses the why and how of events and processes that are connected conceptually, including the use of focusing phenomena that link features of the learning environment to the way in which individuals generalize; (b) ***social framing***, which takes a situated approach to transferring across contexts (i.e., intercontextuality); and (c) Marton and Pang's (2006) focus on the discernment of ***differences*** rather than similarities.

Recent thinking on the degrees or levels of transfer has suggested different schemes. Barnett and Ceci (2002) have defined two dimensions of contextual transfer. Along one dimension are the general categories or types of contexts: (a) knowledge domain, (b) physical context, (c) temporal context, (d) functional context, (e) social context, and (f) modality of transfer (see Figure 3). In each of these categories, the specific contexts range from near to far transfer so that under "knowledge domain" "mouse vs. rat" is an instance of near transfer, while "science vs. art" is an example of far transfer. If we consider transfer in terms of context, an alternative framework of six degrees (or levels) can be depicted as connections within and across contexts as shown in Figure 3. In this diagram, the six degrees of transfer include:

a. *Closely related transfer*, which involves making connections to closely related or proximally located information.
b. *Within context or domain transfer*, which involves connecting more distally related information within the same context.
c. *Within overlapping contexts or domains transfer*, which involves making connections to information that lies in overlapping or embedded contexts. It is important to note here that such transfer makes explicit connections to multiple contexts, as opposed to connections that make no reference to multiple contexts.
d. *Related transcontextual or transdisciplinary transfer*, which involves making connections to a very different context without obvious connections to the initial context.
e. *Distal transcontextual or transdisciplinary transfer*, which involves making connections to contexts that are highly dissimilar and without obvious connections to the initial context.
f. *Novel contextual transfer*, which is related to Haskell's (2001) creative transfer where novel concepts and/or contextual situations are constructed.



	Closely Related Within Context Transfer	Transfer Within Context	Transfer Within Overlapping Contexts	Transfer to Related Contexts	Transfer to Distally Related Contexts	Novel Contextual Transfer
Knowledge Domain	within same or related conceptual area	within same context, but across dissimilar concepts	across contexts that overlap to some degree	across contexts that are more closely related	across contexts that are not closely related	creative construction of novel contexts or concepts
Physical Context	within same space	across different spaces, but within same setting	across settings that overlap to some degree	across similar settings or spaces	across dissimilar settings or spaces	creation of or connection to novel setting or space
Temporal Context	within same time period (minutes)	within same day	within same week	within same focal period (e.g., unit)	over a year or more	many years later
Functional Context	within same specific function or activity	within same functional or activity context	across an overlapping functional or activity context	across similar or closely related functional context	across dissimilar functional context	novel use of or creation of new activity or functional context
Social & Cultural Context	within context of personal activities	within immediate social context	across overlapping social or culture context	across closely related social, political, or cultural contexts	across dissimilar social or cultural contexts	novel connections to very different social contexts
Modality	within same representa-tional modality	across highly related representa-tional modalities	across similar representa-tional modalities	across somewhat dissimilar representa-tional modalities	across highly dissimilar representa-tional modalities	creation of novel representa-tional modality

Near Transfer → **Far Transfer**

Substance of Transfer:

Learned Skill	**Performance**	**Aesthetic &/or Emotional Connection or Perspective**	**Cognitive Processes**	**Conceptual Knowledge & Understanding**	**Abstractions:** Explanatory Principles & Models

[**Portions of this model are adapted from**: Barnett & Ceci, 2002; Bloom, 2007; Lobato, 2006]

Figure 3. Dimensions of the transfer of knowledge.

These six degrees of transfer are specifically related to transfer distance across different contexts, including subject matter domains. In addition, the vertical axis in Figure 2 provides for intersections with dimensions of contextual activity. From this perspective we can focus on what is being transferred and within what physical or temporal context such transfer is taking place. In this project, we will be utilizing this framework as a basis for assessing transfer.

Application of the Model

If any novel approach to teaching and learning is to be successful, teachers must be able to adapt the approach to their own styles and philosophical orientations. They also need to develop a sense of ownership over the new approach. From experiences with my local school district, there is a great deal of variation among teachers. However, this variation appears to involve a degree of hybridization of constructivist, social constructivist, project-based, teacher-directed inquiry, and traditional teacher-directed approaches. As a result, any intervention needs to be successful over a wide variety of teacher characteristics, styles, and practices (Schoen, Cebulla, Finn, & Fi, 2003; Trigwell, Prosser, & Waterhouse, 1999). Since this model relies heavily on holistic and transdisciplinary systems thinking, which has its own underlying philosophical, epistemological, and worldview orientations, it makes sense that the orientations of teachers can influence how the model is implemented and how it will affect student learning and transfer. As suggested by Fenstermacher and Soltis (1998) many teachers are unaware of their particular orientations, which they have acquired through their introductions to and entering into the profession. Whether teachers have carefully constructed their orientations (which is rare according to Barnes, 1992) or have acquired them unintentionally, it will be critically important to identify and examine how each teacher's orientations play-out in the implementation and success of the model.

Conceptual Content

The subject matter content for such an approach can include what is typically taught, along with a major shift in attention to large concepts and patterns that span subject matter disciplines. These large concepts and patterns have been referred to as transdisciplinary and transcontextual concepts and patterns (Bloom, 2006a, 2007; Bloom & Volk, 2007; Davis & Sumara, 2006). Typically, such concepts and patterns are presented either within a specific subject matter context or with minimal contextual connections. However, the focus here is for students to explore and make connections with these concepts and patterns across multiple subject matter disciplines and other contexts, while testing the explanatory power of these concepts transcontextually. These large, transdisciplinary concepts and patterns are addressed separately in various national standards, such as the *National Science Education Standards* (NRC, 1996), *Principles and Standards for School Mathematic* (NCTM, 2000), and *Expectations of Excellence: Curriculum Standards for Social Studies* (NCSS, 2006). However, some examples of how these concepts and patterns appear in different disciplines are delineated in Table 3.

In general, these and many other concepts and patterns are ubiquitous with common fundamental meanings across contexts, as well as more context-specific meanings. The contention is that as students develop understandings of a concept in one context, they can test these understandings or conceptual explanations in other disciplines and contexts. In the process, they will begin to see how the fundamental meanings and explanations can be useful across subject matter areas and other contexts. Such usefulness can lead to enhanced abilities in analyzing data and other information, critical thinking, creative thinking, decoding novel problems and questions, and problem-solving (Bloom & Volk, 2007).

Table 3. Examples of some transdisciplinary and transcontextual concepts and patterns.

CONCEPTS – PATTERNS	**EXAMPLES IN:**			
	Science	**Social Studies**	**Mathematics**	**Other Contexts**
Cycles	biological clocks; circulatory system; mechanical cycles; carbon cycle; water cycle; orbits	economic cycles; election cycles; emotional cycles; cultural rituals	algorithmic cycles; computational cycles	daily routines; gaming cycles;
Regulation – borders and barriers	skin & temperature regulation; membranes and	border security; social barriers; architectural doors and barriers	sets; logical decisions (if-then); asymptote	
Stability & Layering	multicellular organization of structure and function	hierarchical and other layered structures of government and organizations	sequentially layered operations	clothing; paint, blankets; family life; communities
Relationships – 2 or more	cellular interactions; interactions between biological systems; atomic bonding and molecules	person to person relationships; wars and conflicts; international and intercultural relationships; communities	patterns; ratios; sets; graphs	friendships; sports & teams
Change	metamorphosis; development and growth; evolution; erosion; chemical reactions; seasonal	cultural change; social change; traumas;	linear & geometric transformation; modeling	perceptual shifts in art; social fads; death; divorce; breakthroughs
Arrows and Flows	velocity; cyclical flow of energy or materials; force; acceleration; wind; currents; osmosis	traffic patterns and flow; directional power relationships; sequences; migration patterns	vectors; sequences; steps	pilgrimages; journeys; agendas; sports actions (races, football, etc.)

Other Examples:

• time & temporal relations	• clusters, groupings, & accumulations	• gradients, slopes, and continuums	• triggers & initiating factors	• locomotion, transportation & movement	• centers and organizing factors
• continuity	• distribution	• energy	• force	• power	• protection
• adaptation – acclimation	• space and territory	• competition – cooperation	• networks and webs	• rigidity and flexibility	• variation and diversity
• communication	• emergence	• communities	• form: tubes	• form: spheres	• form: sheets

The Teaching Model.

This Depth—Extent—Abstraction Model (DEAM) focuses on children's developing deep understandings and abstractions or explanatory models, as well as utilizing these deep understandings and abstracted models in other contexts and subject matter areas. Deep understandings involve more complex or intricate interconnections both within and between the concepts being studied. In addition, developing such understandings needs to involve the basic components of systems thinking (see Table 1) and pattern thinking (see Table 2). These basic components involve developing understandings of (a) wholes systems and how the parts function together, (b) relationships and interconnections between various relevant concepts or parts, and (c) the influence of specific variables or factors and other associated patterns. The abstraction or model development part of this model also relies heavily upon both systems and pattern thinking with particular emphasis upon the transformation of deep understandings into abstracted models that may focus on specific patterns. The extent component again relies upon both types of thinking including their focuses on evaluating the relationships, patterns, and functions or meanings across contexts. The thinking processes involved in the Extent component require a recursive approach that tests the validity and reliability of their explanations (e.g., the models) across contexts. This process may require reworking explanations over levels of scale. In other words, students may find that a very basic explanatory model may "work" across contexts, but that more context or subject matter specific versions of their explanatory model "work" to better explain specific functions or meanings within each different context. In general, the DEAM model requires teaching that utilizes systems and pattern thinking to help children develop deeper and more complex understandings, develop robust explanatory models that work within and across disciplines, and utilize and test their deeper understanding and explanatory models across subject matters areas and other contexts of personal experience.

An overview of the implementation of this model appears in Figure 4. The fundamental approaches of systems thinking and pattern thinking are used to examine any particular thematic, conceptual, or theoretical strand. At the same time, various teaching approaches can be infused in the implementation of these thinking approaches, while all of these approaches operate within a recursion among extent (or explaining in depth), abstraction (or developing explanatory models), and extent (or transdisciplinary testing and connecting). Ideally, students should be working towards relevant knowledge products.

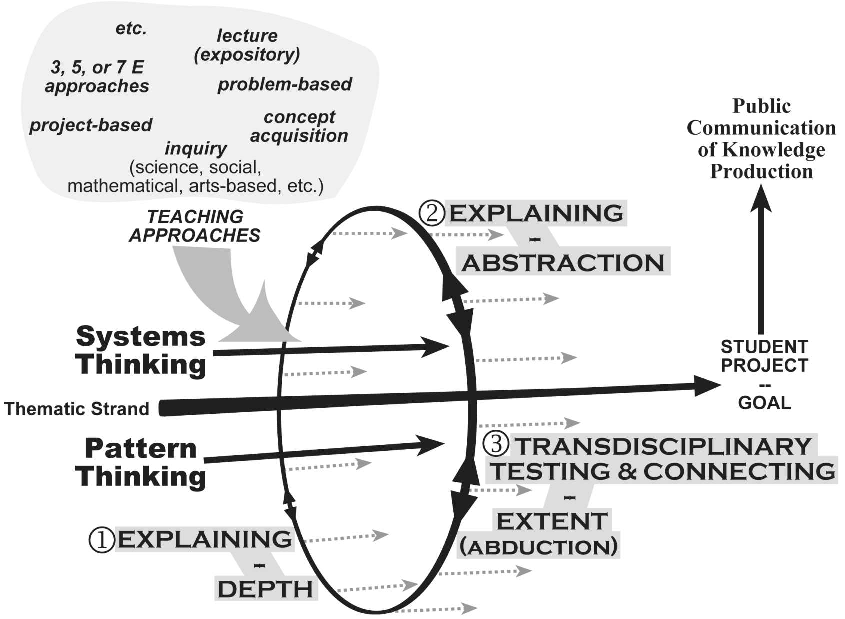


Figure 4. A pedagogical model that incorporates our complex learning model (from Figure 1).

Practical Importance

The practical importance of this approach has to do with children's learning and achievement, as well as with teacher's abilities to adapt the model to their own particular styles. The impacts of this approach, include:

- Impact children's learning:
    - ✦ Increase the complexity and meaningfulness of their understandings.
    - ✦ Increase children's abilities to transfer and utilize knowledge across diverse disciplines and contexts.
    - ✦ Increase children's abilities to think critically and creatively.
    - ✦ Increase children's problem solving abilities.
- Increase children's achievement test scores.
- Provides a teaching model that is adaptable to a variety of teaching styles and approaches, which in turn will allow teachers to take ownership over the model's implementation.
- Provides an approach to teaching and learning that can connect to cultural epistemologies and knowledge, as well as to idiosyncratic meanings across various languages.

Such impacts on learning and teaching can have long-term benefits in terms of providing useful cognitive tools for children's future learning and sense-making. By providing explicit explanations of this model of thinking and learning to students, followed by engaging in using this model to learn and use knowledge in a variety of contexts, students will develop a sophisticated tool for critical and analytical thinking, creative thinking, and problem-solving. Effective and powerful critical, analytical, and creative thinking (which also are used in problem-solving) utilize pattern thinking and systems thinking. By adding abductive thinking, as in our proposed model, these ways of thinking and problem-solving will be taken to another level of power in terms of their transferability across diverse contexts. In a rapidly changing and complex world with increasingly major problems facing the survival of humanity, we need to promote the kind of thinking proposed for this grant project.

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